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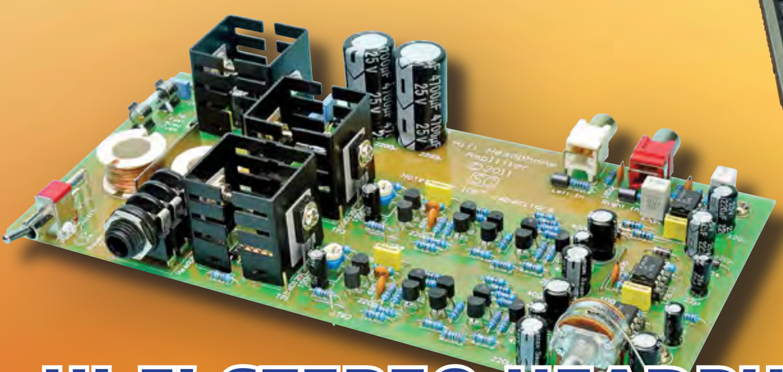

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Our November 2014 issue will be published on Thursday 2 October 2014, see page 72 for details.

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

4-Channel Serial Port Temperature Monitor & Controller Relay Board

4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application.
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Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
*Kit Order Code: 3187KT - **£39.95***
*Assembled Order Code: AS3187 - **£49.95***

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Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
*Kit Order Code: K8036 - **£24.70***
*Assembled Order Code: VM106 - **£36.53***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
*Kit Order Code: 3067KT - **£19.95***
*Assembled Order Code: AS3067 - **£27.95***

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
*Kit Order Code: 3166v2KT - **£23.95***
*Assembled Order Code: AS3166v2 - **£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
*Kit Order Code: 3179KT - **£17.95***
*Assembled Order Code: AS3179 - **£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
*Kit Order Code: 3158KT - **£24.95***
*Assembled Order Code: AS3158 - **£34.95***

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
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See website for lots more DC, AC and stepper motor drivers!

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We can supply back issues of *EPE* by post, most issues from the past five years are available. An *EPE* index for the last five years is also available at **www.epemag.com**. Where we are unable to provide a back issue a photocopy of any one article (or one part of a series) can be purchased for the same price. Issues from Jan. 99 are available on CD-ROM or DVD-ROM – and back issues from recent years are also available to download from **www.epemag.com**. Please make sure all components are still available before commencing any project from a back-dated issue.

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PROJECTS • Driveway Sentry • Milliohm Meter Adaptor For DMMs • Build A Vox • Superb Four-Channel Amplifier – On The Cheap

FEATURES • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • Net Work • Computer Error: Reliable Digital Processing – Part 1

SEPT '13

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OCT '13

PROJECTS • LED Musicolour – Part 1 • High-Temperature Thermometer/Thermostat • Ingenuity Unlimited

FEATURES • Teach-In 2014 – Part 1 • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • Net Work • Computer Error: Reliable Digital Processing – Part 3

NOV '13

PROJECTS • CLASSiC-D Amplifier – Part 1 • LED Musicolour – Part 2 • Mains Timer For Fans Or Lights • Ingenuity Unlimited

FEATURES • Teach-In 2014 – Part 2 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • Net Work

DEC '13

PROJECTS • Six Test Instruments In One Tiny Box • Virtins Technology Multi-Instrument 3.2 • CLASSiC-D Amplifier – Part 2 •

FEATURES • Teach-In 2014 – Part 3 • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • Net Work

JAN '14

PROJECTS • 2.5GHz 12-Digit Frequency Counter With Add-on GPS Accuracy – Part 1 • The Champion Amplifier • Simple 1.5A Switching Regulator •

FEATURES • Teach-In 2014 – Part 4 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • Net Work • PIC N' Mix • Net Work

FEB '14

PROJECTS • High-energy Electronic Ignition System – Part 1 • Mobile Phone Loud Ringer! • 2.5GHz 12-Digit Frequency Counter With Add-on GPS Accuracy – Part 2

FEATURES • Teach-In 2014 – Part 5 • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • Net Work • PIC N' Mix • Net Work

MAR '14

PROJECTS • Infrasound Detector • Extremely Accurate GPS 1pps Timebase For A Frequency Counter • High-energy Electronic Ignition System – Part 2 • Automatic Points Controller For Your Model Railway Layout

FEATURES • Teach-In 2014 – Part 6 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • Net Work • PIC N' Mix • Net Work

APR '14

PROJECTS • Jacobs Ladder • Deluxe GPS 1pps Timebase For Frequency Counters • Capacitor Discharge Unit For Twin-Coil Points Motors

FEATURES • Teach-In 2014 – Part 7 • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • Net Work • PIC N' Mix • Net Work • Beta-Layout's Re-Flow Oven Kit And Controller review

MAY '14

PROJECTS • Rugged Battery Charger • CLASSiC-D ±35V DC-DC Converter • Digital Multimeter Auto Power-Down • Control Relays Over The Internet With Arduino

FEATURES • Teach-In 2014 – Part 8 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • Net Work • PIC N' Mix • Net Work •

JUNE '14

PROJECTS • Cranial Electrical Stimulation Unit • Mini Audio Mixer • Adding Voltage And Current Meters To The Bits 'N' Pieces Battery Charger •

FEATURES • Teach-In 2014 – Part 9 • Techno Talk • Circuit Surgery • Interface • Max's Cool Beans • PIC N' Mix • Net Work •

JULY '14

PROJECTS • Versatile 10-Channel Remote Control Receiver • Li'l Pulser Model Train Controller • Two Demonstration Circuits For Human Colour Vision •

FEATURES • Teach-In 2014 – Part 10 • Techno Talk • Circuit Surgery • Practically Speaking • Max's Cool Beans • PIC N' Mix • Net Work • Audio Out •

AUG '14

PROJECTS • Active RF Detector Probe For DMMs • Add A UHF Link To A Universal Remote Control • PCBirdies • USB Port Voltage Checker • iPod Charger Adaptor •

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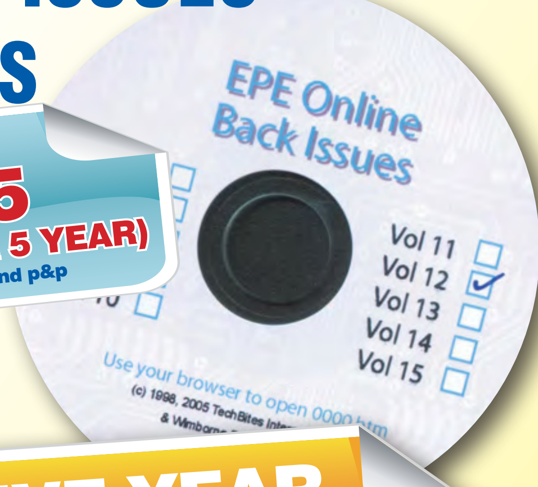

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EPE online

I wanted to take this opportunity to remind our readers about *EPE's* website at **www.epemag.com**, which offers information about current and previous issues of *EPE*, as well as being a gateway to our other services. On the 'Projects' pages the cover shots of *EPE* are displayed and you can visit the monthly web pages with links to source code and more details. The website is also the place to view any updates or errata for specific projects, and we go to great lengths to archive information with the interests of future readers in mind. *Net Work* columnist Alan Winstanley is our webmaster, and he has managed to upload legacy magazine details in the 'Library' that date all the way back to 1998. This is a vast and valuable resource, and I urge all readers to make the most of it.

Supporting readers

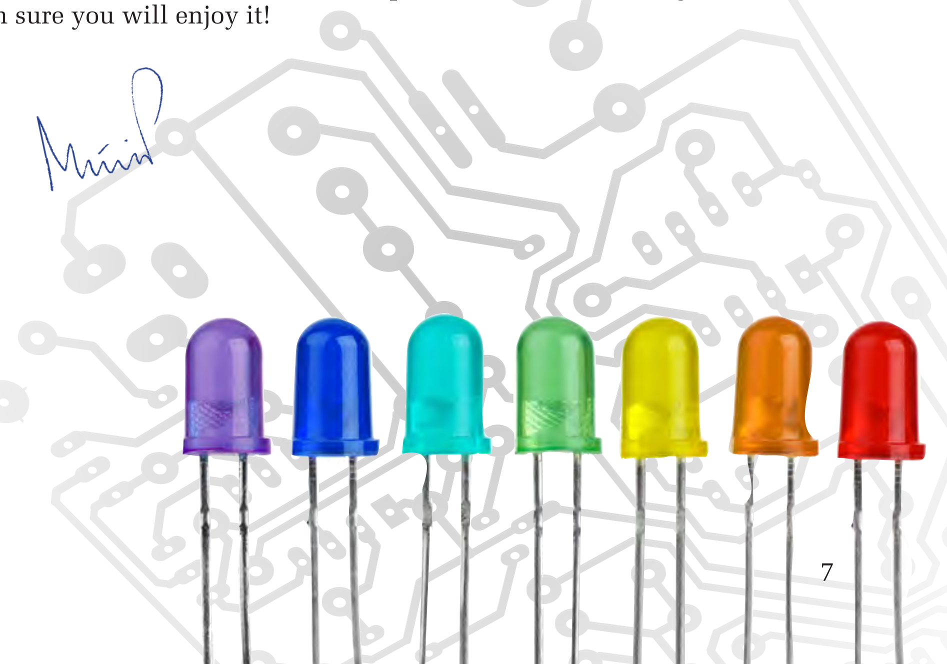
We receive a large number of enquiries from overseas or queries about magazine availability, source code or PCB artwork. Due to the continuous evolution of *EPE* over the years, providing a consistent online resource has not been easy, but many regular questions are now addressed in the Help page available via our Library. As always, there is never a query that a quick email to us will not resolve, but do have a look around the *EPE* website – you might be surprised by the amount of information that is just a click away.

Chat among yourselves!

I couldn't discuss *EPE* and the Internet without mentioning *Chat Zone*, our online forum for all things *EPE* and electronics related. Just click over to **www.chatzones.co.uk** and sign up to enter a world of free help and friendly kindred spirits. We have fora dedicated to Raspberry Pi, old projects, *Teach-In* and just about anything else of relevance to *EPE* readers.

Teach-In 2015

Father-and-son team Mike and Richard Tooley scored a hit this year with their popular *Teach-In* series on Raspberry Pi, and following on from that I have three good pieces of news. First, they are currently writing a further article on the latest version of Pi – the 'B+' upgrade. Second, the whole series is to be published in one handy publication – the perfect present for you or an electronics friend. Last, but not least, we have just agreed to start the next *Teach-In* series in early 2015. I won't tell you what it's about, I need to be 'discrete' and not spoil the fun. That's enough of a hint – I'm sure you will enjoy it!



NEWS

A roundup of the latest Everyday News from the world of electronics

Broadband without landlines – report by Barry Fox

UK chipmaker CSR is hoping to steal a march on the ZigBee radio control system with a new approach based on Bluetooth Smart. CSR Mesh works as a mesh radio network – just like ZigBee – but without the need for an additional network hub, or router. This is possible, CSR says, because all modern smartphones and tablets come with Bluetooth Smart capability 'out of the box'.

Smartphone control

CSR Mesh lets one smartphone control a virtually unlimited number of devices, such as lights, heating or security, with plug and play set-up. CSR is now pledging to donate its Smart Mesh technology to SIG (the Bluetooth Special Interest Group) on a no-royalty basis.

Speaking at 'The Future is Smart' exhibition recently staged in London by SIG, Rick Walker, senior product marketing manager for CSR in Cambridge, UK, demonstrated a prototype LED home lighting system similar to Philips Hue, but using Mesh instead of ZigBee.

He told us: 'CSR Mesh is disruptive. It puts the smartphone at the centre of the Internet of Things. We developed a software protocol that runs over the Smart standard to create a mesh network at the standard Bluetooth frequency of 2.4GHz, controlled by standard Bluetooth hardware.

'But we know that now we have shown what can be done there are some big nasty competitors out there that will want to develop their own systems and fragment the market. We want to avoid a situation like the zillion different standards for Wi-Fi, so we will donate our technology to SIG and let SIG give free licences.

'We first announced the system in February and will publish technical details and examples of use on our website. Then, early next year, we will offer everything, except the source code, to SIG to licence without royalties. But we will be giving away the source code for Android and Apple iOS apps.

'The way we will earn revenue is purely through the silicon we sell. The Mesh chips will cost around $1 or modules for Mesh devices $5'

CSR Development Kit – designed to accelerate Internet of Things product development

No hub or bridge

ZigBee uses a hub or bridge to convert Bluetooth or Wi-Fi control signals from a smartphone into ZigBee signals that control ZigBee-enabled devices such as lights. With Bluetooth Smart Mesh, an app on the smartphone intelligently configures a Bluetooth mesh so that Bluetooth signals from one Bluetooth-enabled device are sent on to other enabled devices. The app can address each device individually, or in groups, for instance – as demonstrated at the SIG event – to switch lamps on and off or dim them or change their colour.

128-bit AES encryption securely prevents access to the mesh until the user has given authorisation, for instance by scanning a QR code on the device with the smartphone.

Bluetooth Smart standard with low power use

The Bluetooth Smart standard uses the same frequencies and powers as conventional Class 2 Bluetooth, but adopts a modified data-handling scheme to save power. For instance, a Bluetooth Smart device intermittently transmits bursts of control information, instead of constantly streaming at high rates. This, along with the use of very low power processors, can extend Smart range from the normal Bluetooth distance of under 10m to around 25m, and lets wearable devices run for up to a year on a single coin cell.

CSR is now offering hardware and software Mesh development kits for $299, see: **www.csr.com/contact/sales-representatives**.

'We are already working with all the big names that are currently using ZigBee' said Rick Walker. 'Are we talking to Philips about using it for Hue? Absolutely.'

I asked Philips about using CSR Mesh for Hue and got back an answer, which clearly indicated that whoever wrote it did not understand how CSR Mesh works.

'Hue enables control from anywhere in the house and "out-of-home", and not a short-ranged room-based technology… we can expand with a full range of switches (eg, tap) and sensors to control lights in new and innovative ways instead of one device (smartphone)… (Using) ZigBee LightLink means that interoperability between devices from different brands is possible. Bluetooth is only about connectivity and does not enable interoperability on complete products.'

Poorly informed comments like this do a company like Philips no favours at all.

Minty Geek launches minty fresh new website

Looking for a back-to-school present for a budding electronic engineer? Minty Geek, a Somerset-based provider of electronics kits for education and learning, has launched a new website at **www.mintygeek.com** where customers can access the company's range of projects and interact with others via free membership of the Minty Geek club. The website provides access to all the latest products and information with a shop for kits and components – as well as downloads for instruction manuals and software packages.

Minty Geek is the brainchild of Mark Brickley, whose inspiration came from the frustration of trying to find a suitable torch for another hobby – astronomy – and ended up making one for himself. Thus was born the prototype for 'Torch in a tin' with all the components needed supplied in a mint tin. Since then the company has introduced other electronics learning projects with varying levels of complexity to help budding enthusiasts get to grips with the basics of electronics.

Microchip – CSR Bluetooth partnership

Microchip, a leading provider of microcontroller, mixed-signal, analogue and Flash-IP solutions has developed the BLE RN4020 module, an easy-to-use and complete turnkey solution, which takes CSR's proven and highly flexible Bluetooth Smart ICs to a wide range of customers.

The module gives developers access to CSR's market-leading Bluetooth Smart technology and is supported by Microchip's MPLAB X Integrated Development Environment, which provides developers with access to a large library of example Bluetooth Smart development code. This eases and accelerates prototype production and enables developers to get their products to market quicker.

Microchip chose CSR as a Bluetooth Smart chip supplier due to CSR's strong reputation for Bluetooth technology and because the two companies share an established history of supporting customers through to the end of a product's lifecycle.

CSR1012 provides a smaller form factor package ensuring that the module has minimal impact on size-constrained designs, measuring just 11.5 × 19.5 × 2.5mm. The RN4020 module has a built-in PCB antenna with 7dBm transmit power and a receive sensitivity of –92.5dBm, enabling operation over 100 metres.

The RN4020 PICtail is a development tool for prototyping new designs using the Microchip RN4020 Bluetooth Module. The PICtail has an onboard PIC18 to provide USB serial communications, allowing it to connect directly to a PC for simple demonstrations using RN4020 scripting capabilities

Scientists develop spray-on solar cells

Experts from Sheffield University's Department of Physics and Astronomy and Department of Chemical and Biological Engineering have developed a technique for spray-painting solar cells using 'perovskite', a very promising new material for solar cells.

The spray-painting process wastes very little of the perovskite material and can be scaled to high volume manufacturing – similar to applying paint to cars and graphic printing.

Lead researcher Professor David Lidzey said: 'There is a lot of excitement around perovskite-based photovoltaics.

'Remarkably, this class of material offers the potential to combine the high performance of mature solar cell technologies with the low embedded energy costs of production of organic photovoltaics.'

While most solar cells are manufactured using energy intensive materials like silicon, perovskites, by comparison, requires much less energy to make. By spray-painting the perovskite layer in air the team hopes the overall energy used to make a solar cell can be reduced further.

Professor Lidzey said: 'The best certified efficiencies from organic solar cells are around 10 per cent.

'Perovskite cells now have efficiencies of up to 19 per cent. This is not so far behind that of silicon at 25 per cent – the material that dominates the world-wide solar market.'

ERRATA – *Timer for Fans and Lights project* (November 2013)

Constructors of this project should not wire up the unit as shown in Fig.1(c) on page 31, with a load from the 'Lsw' terminal to neutral. This will destroy the unit. If you need to wire up a fan and light, connect them in parallel between the 'Lload' terminal and neutral. Please go to *Chat Zone* for a discussion of this project: **www.chatzone.co.uk**

Brother launches electrical label printer

Printer company Brother has launched a new label printer for electricians or hobbyists with extra complicated wiring. The PT-E550WVP produces durable labels up to 24mm wide that are resistant to water, abrasion and extreme temperatures. This helps ensure that wires and other equipment, including fuse boxes, sockets, and health and safety signage, is correctly labelled, easily identifiable, and keeps with the identification requirements of the wiring regulations.

The label printer features wireless connectivity, meaning that information, such as symbols, logos and databases, can be instantly transferred from mobile devices or PCs and stored on the machine. This can then be used to produce labels quickly and easily.

The machine includes a half-cut feature, ensuring tape wastage is minimal, as well as a large backlit LCD display, which is perfect for use in dark places, and a QWERTY keyboard for easy data entry.

SiDRADIO: an integrated using a DVB-T dongle

. . . incorporating a tuned RF preselector, an up-converter and coverage from DC to daylight

Part 1: By JIM ROWE

Below: nearly all the parts for the SiDRADIO are mounted on a single large PCB. The DVB-T dongle plugs directly into an internal USB port and is housed together with the PCB in a low-profile instrument case.

SDR

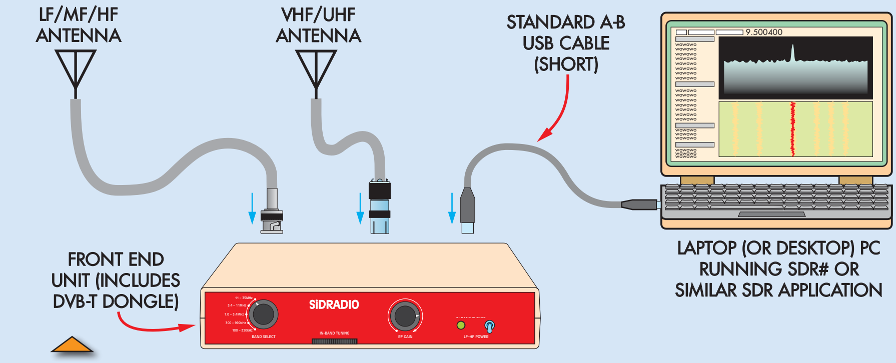


Fig.1: the SiDRADIO has inputs for LF/MF/HF and VHF/UHF antennas, and is connected to a PC running SDR# (or similar) via a standard USB cable.

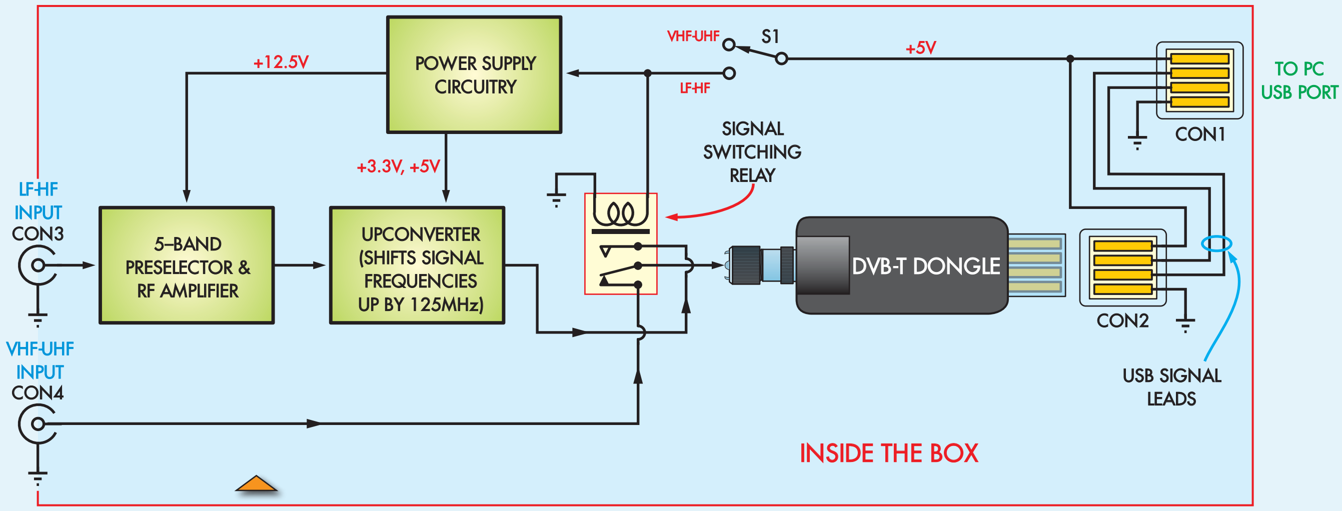


Fig.2: block diagram of the SiDRADIO. It includes a 5-band tuned RF preselector and amplifier, an up-converter and the DVB-T dongle all in one box. The up-converter shifts LF-HF signals up by 125MHz so that they can be tuned by the DVB-T dongle.

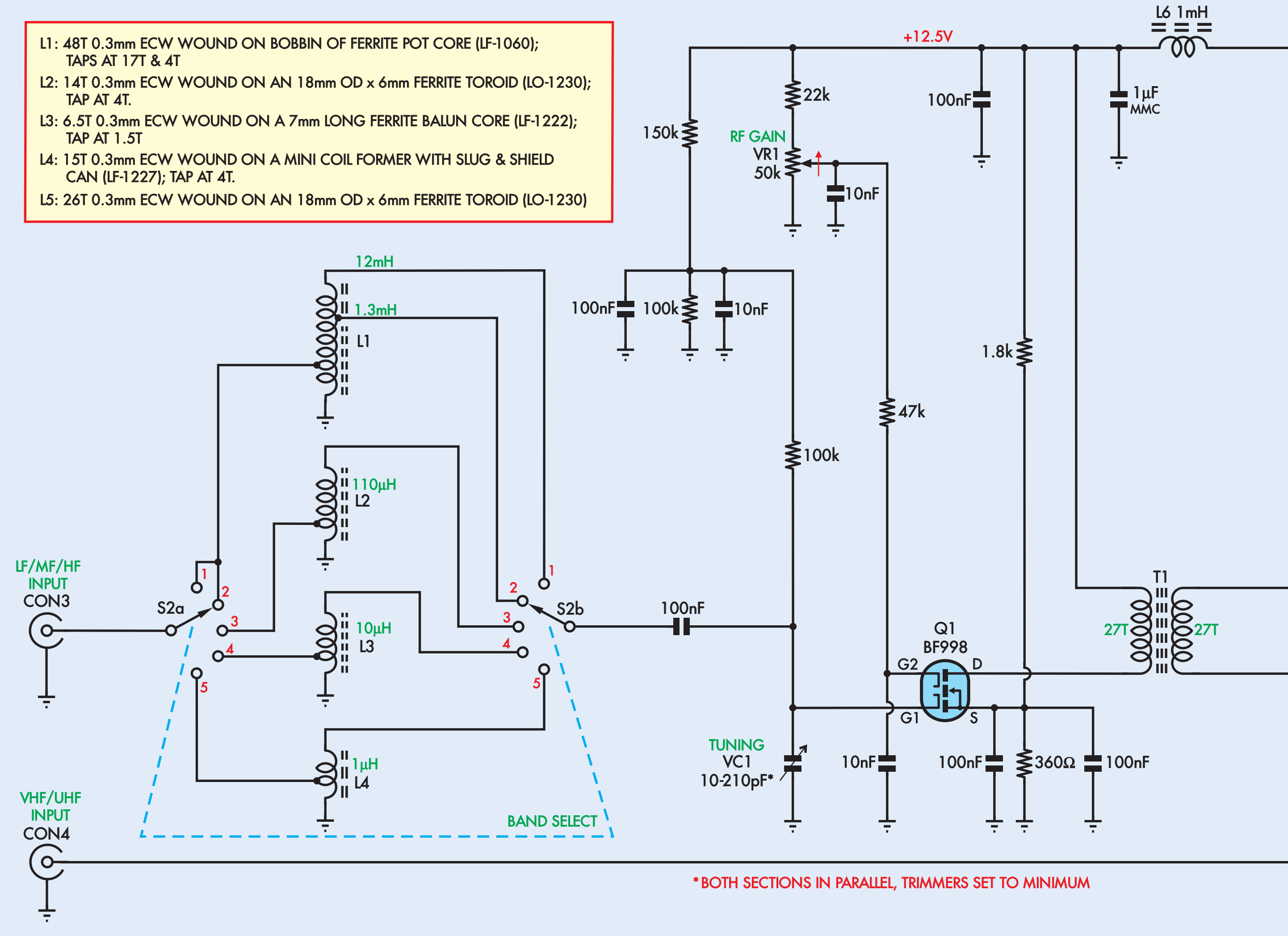
SiDRADIO is a low-cost communications receiver with coverage from 100kHz to over 2GHz. It is self-contained, housing a USB DVB-T dongle plus all the circuitry for an up-converter and RF preselector, and is powered from your PC via the USB cable.

IF YOU ARE JUST dipping your toe into the world of radio communications, you won't want to spend much money. However, a fully-fledged communications radio is an expensive acquisition.

Fortunately, software-defined radios have radically changed the whole communications scene. This has been further shaken up by the fact that cheap and readily available USB DVB-T dongles, normally used for watching digital TV on a personal computer, can now be configured as communications radios with a wide range of reception modes: FM, AM, SSB, CW etc. Not only that, but the SDR# software provides fancy features such as spectrum analyser and waterfall displays on your PC's screen.

We have seen designs for a cheap and cheerful approach to a software-designed radio (SDR) and a matching up-converter to enable a DVB-T dongle to receive frequencies below about 52MHz.

We felt we could do betther, with extra features such as band-switching



SiDRADIO

Fig.3: the circuit diagram of the SiDRADIO. The tuned RF front-end is based on coils L1-L4 and tuning capacitor VC1. Q1 amplifies the tuned RF signal and feeds it via T1 to the up-converter, which is based on an SA612AD/01 or SA602AD/01 double-balanced mixer (IC1) and oscillator XO1. IC1 then feeds the antenna input of the DVB-T dongle via relay RLY1.

and tuning, gain on the frequency bands covered by the up-converter and ease of operation, so that you don't have to juggle input cables, supply switching and so on. We wanted to dispense with the need for a string of small boxes hooked up to the PC: the DVB-T dongle, the LF-HF up-converter and either an active antenna or an RF preamp and preselector. Plus, you also need two antennas and a power supply for the up-converter and the proposed RF preamp/preselector. This could easily end up as an untidy mess of boxes and cables hooked to your PC.

With SiDRADIO (**S**oftware **I**ntegrated and **D**efined **R**adio), we have come up with what is effectively a low-cost integrated communications receiver. It combines a DVB-T dongle (whichever one you want to use) with an LF-HF up-converter (including an HF/VHF signal-switching relay circuit) and an RF preamp/preselector, with it all powered from the PC via a single USB cable.

The 5-band RF preamp and preselector circuit gives improved reception on the LF-HF bands from 100kHz to beyond 35MHz.

Integrated SDR concept

Fig.1 shows how SiDRADIO is connected to your computer. To cover all the available bands, you will need a VHF/UHF antenna and an LF-HF antenna and these are both connected to their respective sockets on the rear panel. Also on the rear panel is a USB socket so that you can hook it up to your laptop or desktop PC. No other cables are required, so it is very straightforward to connect it all together and then listen to the world.

On the front panel is a 5-position band switch, a thumb-operated knob for band tuning and a gain control knob. On the righthand side of the front panel is a toggle switch that allows you to switch between the two antennas via an internal relay – ie, there's no need to disconnect antennas.

All of the components and circuitry for SiDRADIO are built on a double-sided PCB available from the *EPE PCB Service* measuring 197 × 156mm, which is housed (along with the dongle) in a low cost 'low profile' ABS instrument case measuring 225 × 165 × 40mm (W × D × H).

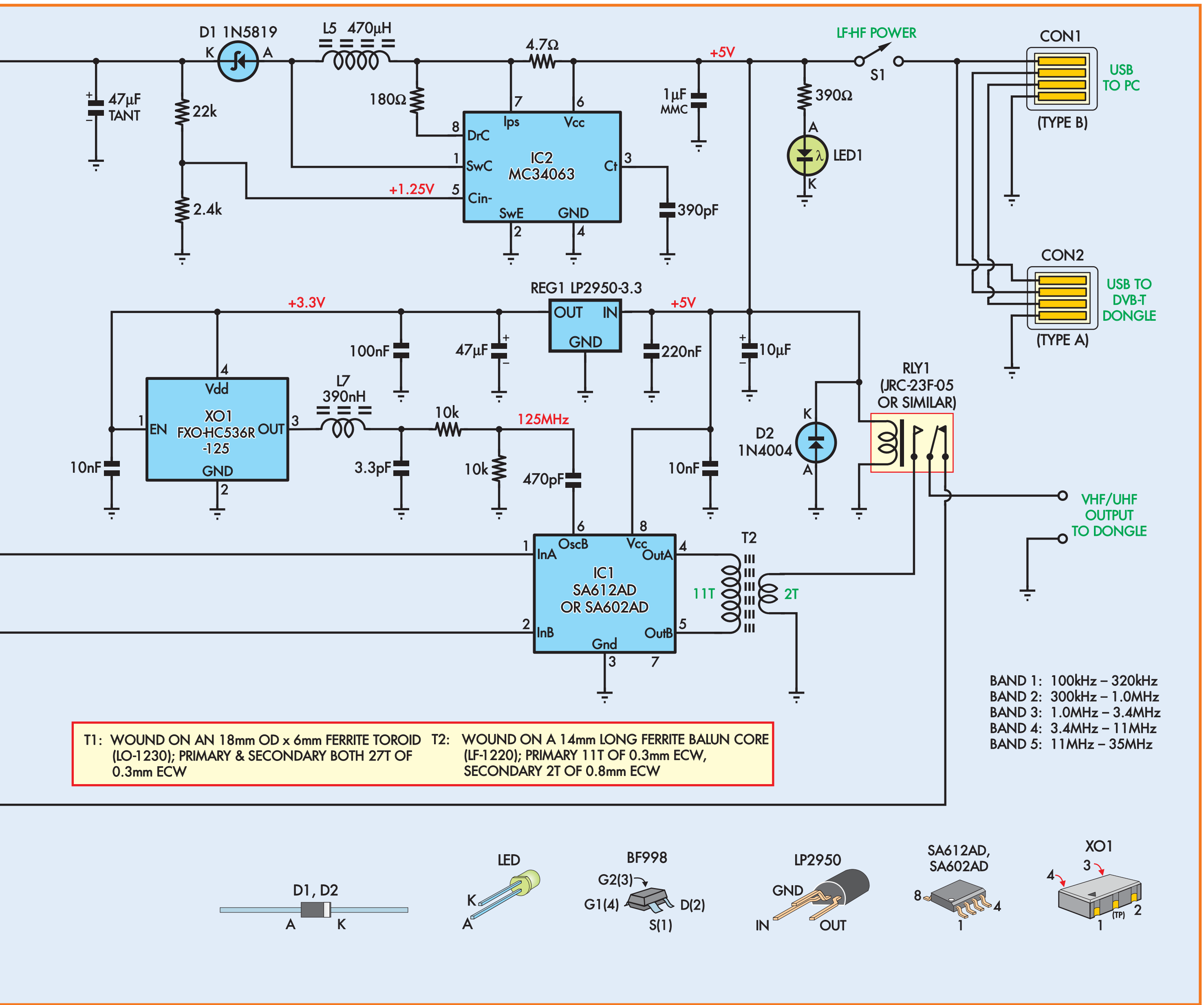


Fig.2 is the block diagram of the SiDRADIO and shows all the circuit sections, including the USB DVB-T dongle. Note switch S1 – it switches power to the circuitry and controls a relay which selects either the output signal from the up-converter or the signal from the VHF-UHF antenna.

The selected signal is fed to the USB dongle for processing and its output is fed via the USB cable to the computer. Note that the USB cable also feeds power to the circuitry.

Table 1: Common DVB-T Dongle Tuner Chips & Their Frequency Ranges

Tuner Chip	Frequency Range	DVB-T dongle model in which chip is found
Elonics E4000	52 – 2200MHz*	EzCAP EzTV668 DVB-T/FM/DAB, many current 'no name' devices
Rafael Micro R820T	24 – 1766MHz	? (not known – but may be in many future dongles)
Fitipower FC0013	22 – 1100MHz	EzCAP EzTV645 DVB-T/FM/DAB, Kaiser Baas KBA010008 TV Stick
Fitipower FC0012	22 – 948MHz	Many of the earlier DVB-T dongles

*With a gap from 1100MHz to 1250MHz (approx) NOTE: Elonics may have ceased manufacture

Circuit details

The full circuit diagram of our SiDRADIO is shown in Fig.3. The up-converter's input transformer T1 is fed from the output of the RF preamp and preselector section, the circuitry on the lefthand side of Fig.3 and based around Q1, a BF998 dual-gate VHF depletion-mode MOSFET.

Q1 is configured as a standard common-source RF amplifier, with the incoming RF signals fed to gate G1 and the transistor's gain varied by adjusting the DC bias voltage applied to gate G2, using 50kΩ pot VR1. The output signal appears at Q1's drain, and is fed directly to the primary of T1.

Q1 therefore acts as an RF preamplifier, with VR1 able to adjust its gain from virtually zero up to approximately +20dB. It may seem strange to have a preamp whose gain can be reduced down to zero, but having the gain variable over a wide range is essential to reduce overloading and cross-modulation from very strong signals.

Because Q1 performs best in this kind of circuit with a +12V DC supply,

DVB-T tuner dongles can be purchased online quite cheaply. These three units all feature a 75-ohm Belling-Lee antenna socket but many other dongles come with a much smaller MCX connector.

we are using a DC-DC step-up converter to derive this +12V from the +5V USB supply fed in via CON1. It's basically a simple boost converter using IC2, an MC34063, together with inductor L5 and Schottky diode D1.

The output of the converter is about +12.5V (12.2-13.2V range), as measured across the 47µF tantalum capacitor.

The DC-DC converter operates at between 50kHz to 60kHz and as a result its output voltage carries a significant amount of ripple at these frequencies. To minimise interference to the RF preamp due to harmonics of this ripple (especially on the lowest 100-320kHz band), the converter's output is filtered using RF choke L6 (1mH) and its accompanying 1µF capacitor. These form a low-pass LC filter with a corner frequency of around 5kHz.

Shielding

Also critical to the circuit's performance is the shielding we have had to provide between the converter's circuitry (especially L5) and the RF preamp and preselector circuitry. We will discuss this shielding later.

The 5-position 2-pole switch (S2a/S2b), coils L1-L4 and tuning capacitor VC1 form the preselector section of the circuit. This is connected between LF-HF antenna input connector CON3 and the preamplifier input. Coils L1-L4 are used to cover each of the five bands, with L1 tapped so that it can be used to cover both of the lower bands. Tuning within each band is then carried out using VC1.

Switch S2a connects the antenna input to the input tap on each coil, while S2b connects tuning capacitor VC1 and the preamp input to the 'top' of each coil. Note that the 'Q' of each coil is relatively modest, so the tuning of VC1 is fairly broad rather than sharp and critical. This is especially the case with coil L1.

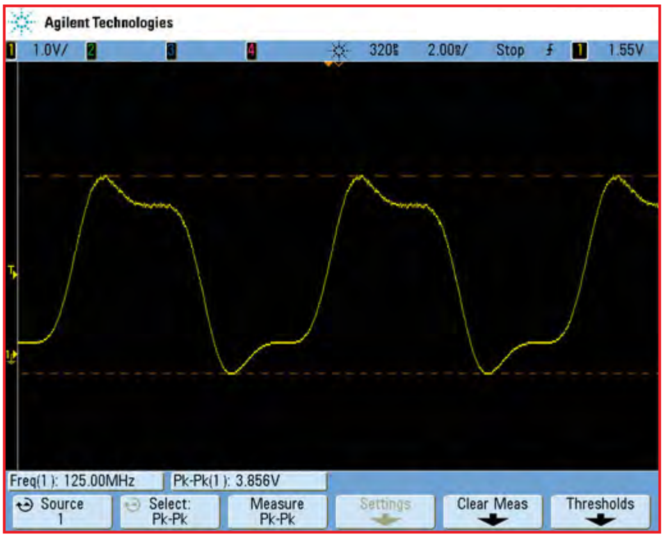


Fig.4: this scope grab shows the 125MHz signal from the crystal oscillator. This was measured using a 400MHz probe and a 350MHz scope, so many of the upper harmonics have been heavily attenuated. Even so, it can be seen that the waveform is far from sinusoidal and that's why it's followed by an LC filter to clean it up and so reduce spurious responses.

Up-converter operation

The frequency conversion is performed by IC1, which is an SA612AD or its close relative the SA602AD. Both are double-balanced mixer devices designed specifically for this kind of use. The LF-HF signals to be up-converted enter the circuit from the RF preamp via matching transformer T1, before being fed into the balanced inputs (pins 1 and 2) of IC1.

The 125MHz signal used to 'shift' the input signals up in frequency is generated by crystal oscillator module XO1, a very small HCMOS SMD device which produces a 125MHz clock signal at its pin 3 output. The output voltage at this pin is 2.65V peak-to-peak, which is rather too high for linear operation of the mixer. In addition, it's essentially a square wave, rich in harmonics of 125MHz as well as the fundamental. You can see its output in the scope grab shown in Fig.4.

As a result, this 'squarish' 125MHz signal is fed through a low-pass filter formed by a 390nH inductor and 3.3pF capacitor, to filter out most of the harmonics. These would otherwise contribute to spurious signals via cross-modulation in the mixer. Then we reduce the filtered 125MHz signal down to a more suitable level for the mixer, via a voltage divider consisting of two 10kΩ resistors.

The signal is then fed into the oscillator input (pin 6) of IC1 via a 470pF coupling capacitor.

Inside the mixer, the balanced input signals at pins 1 and 2 are mixed with the 125MHz oscillator signal at pin 6. The resulting mixing products appear in balanced form at the outputs (pins 4 and 5).

Because IC1 is a double-balanced mixer based on a Gilbert cell, the outputs contain very little of the original input signal frequencies F_{in} or the oscillator signal frequency F_{osc} (125MHz). Mainly, they contain the 'sum' and 'difference' products, ie:

Sum product = $(F_{osc} + F_{in})$
Difference product = $(F_{osc} – F_{in})$

It's the sum product that we want. Although the difference product is also present in the outputs, the signals it

contains are in a different tuning range so they can be ignored.

The balanced output signals from the mixer are passed through a second matching transformer, T2. As well as stepping them down in impedance level (1500Ω:75Ω), T2 also converts them into unbalanced form to provide better matching to the input of the DVB-T dongle.

The output signals from T2 are not taken directly to the dongle input but instead to the normally open contact of relay RLY1. It's the moving common contact of RLY1 which connects to the dongle, and since the actuator coil of RLY1 is driven by the +5V supply line when switch S1 is closed, this means that the up-converter's output is only connected to the dongle when power is applied via S1. This mode is indicated by LED1 being lit.

When S1 is switched off and +5V power is not applied, the moving contact of RLY1 connects to the normally closed contact and this connects directly to the converter's VHF/UHF input connector CON4 at lower left. So when S1 is turned off to remove power from the LF-HF front-end circuitry, the input of the DVB-T dongle is connected directly to the VHF/UHF antenna, as noted above in the brief discussion of Fig.2.

IC1 and RLY1 operate directly from the nominal +5V USB rail, with diode D2 used to absorb any back-EMF spikes which may be generated by the coil of RLY1 when power is removed. Crystal oscillator module XO1 operates from +3.3V and this is derived by REG1, an LP2950-3.3 LDO (low drop-out) device in a TO-92 package.

That's about it, apart from mentioning that the DVB-T dongle is always connected to the USB port of your PC regardless of the position of S1. That's because USB connectors CON1 and CON2 are linked together. This means that providing the USB cable remains plugged into CON1 and the PC's port, the dongle is always powered up and operating.

So, effectively, S1 acts as a band-select switch, with the dongle receiving LF-HF signals when S1 is in the on position and VHF/UHF signals when it is off.

Construction

All the parts except for bandswitch S2 and the VHF-UHF input connector

The SDR# application and its features

SDR# is an easy-to-use software application designed to turn almost any PC into a powerful SDR (software defined radio), using either a DVB-T dongle (the hardware 'front end') or other devices. Here are some of its salient features:

(1) RF performance, frequency accuracy: the RF performance basically depends on the chips used in the DVB-T dongle used with SDR#. A typical dongle fitted with the Elonics E4000 tuner chip can tune from 52-1100MHz and 1250-2200MHz, with a sensitivity of approximately 1.5μV for 12dB of quieting at frequencies up to about 180MHz, rising to about 20μV for the same degree of quieting at 990MHz.

The SDR# software used with the dongle provides a 'frequency correction' feature, whereby you can correct for any frequency error in the DVB-T dongle. In addition, there is a 'frequency shift' feature, allowing you to display the correct frequencies even when you have an up-converter connected ahead of the dongle.

(2) Demodulation modes: AM (amplitude modulation), NFM (narrow frequency modulation), WFM (wide frequency modulation), LSB (lower sideband), USB (upper sideband), DSB (double sideband), CW-L (carrier wave with BFO on low side) and CW-U (carrier wave with BFO on high side).

In all these modes, the RF filter bandwidth can be adjusted over a wide range, while the filter type can be selected from a range of five (Hamming, Blackman, Blackman-Harris, Hann-Poisson or Youssef). The filter order can also be selected over a wide range. In both CW modes, the frequency separation of the software BFO can also be adjusted. There is adjustable squelch and also both linear and 'hang' AGC.

(3) FFT spectrum display and/or waterfall spectrum/time display: the FFT spectrum display and waterfall display can be selected either separately or together. The windowing function used can be selected from six choices: None, Hamming, Blackman, Blackman-Harris, Hamm-Poisson or Youssef, and the display resolution can be adjusted over a wide range by changing the block size from 512 to 4,194,304, in powers of two, with the higher resolutions requiring greater processing overhead.

Good results can be achieved with the default resolution of 4096, which was used for the screen grab shown below.

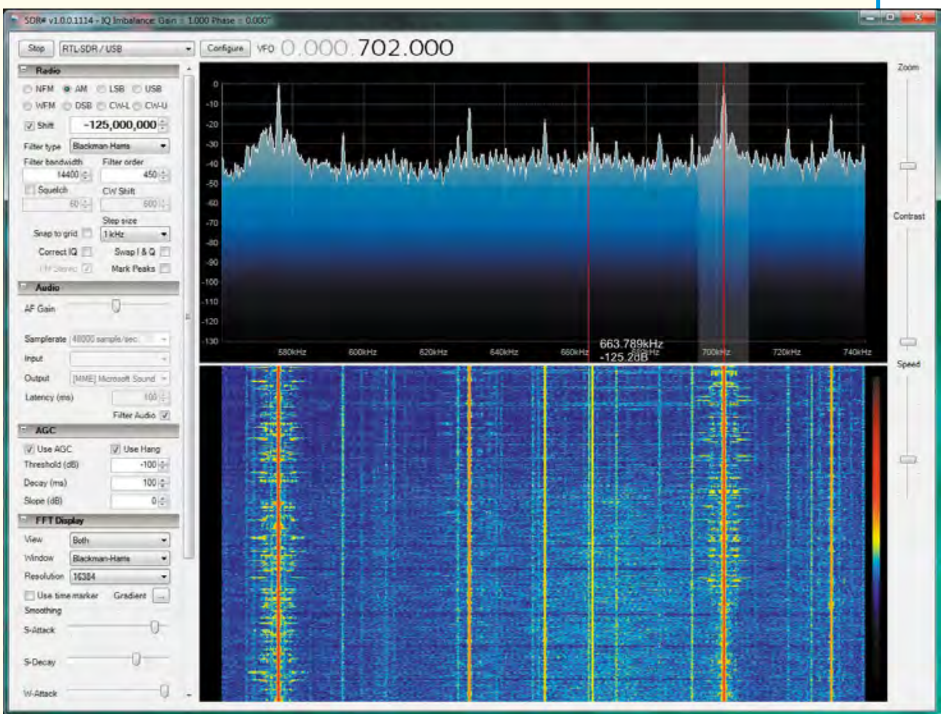


Fig.5: SDR# spectrum and waterfall displays for a 702kHz AM signal. Note that a frequency shift of 125MHz has been entered (at top right) so that the correct tuned frequency is displayed.

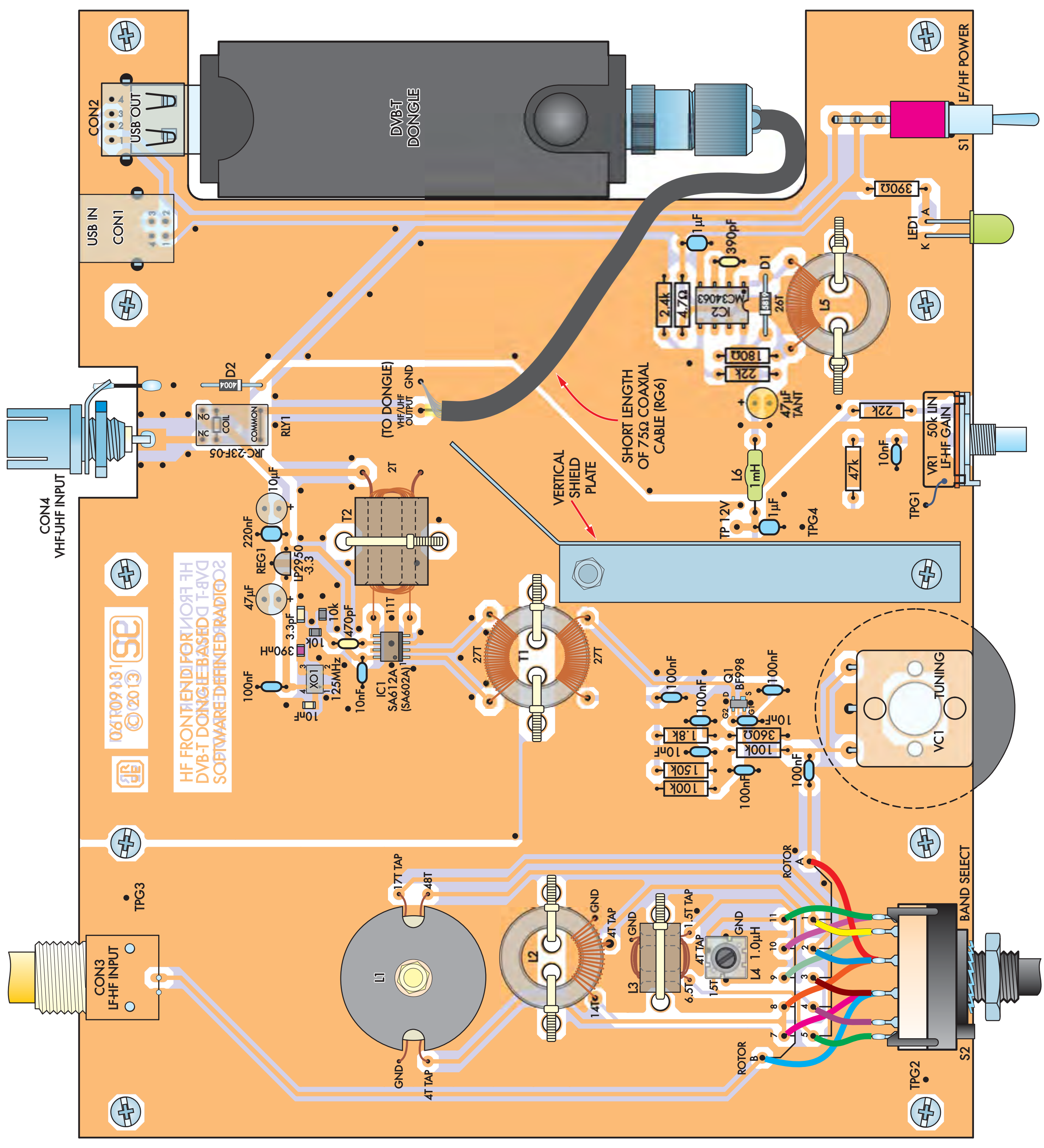


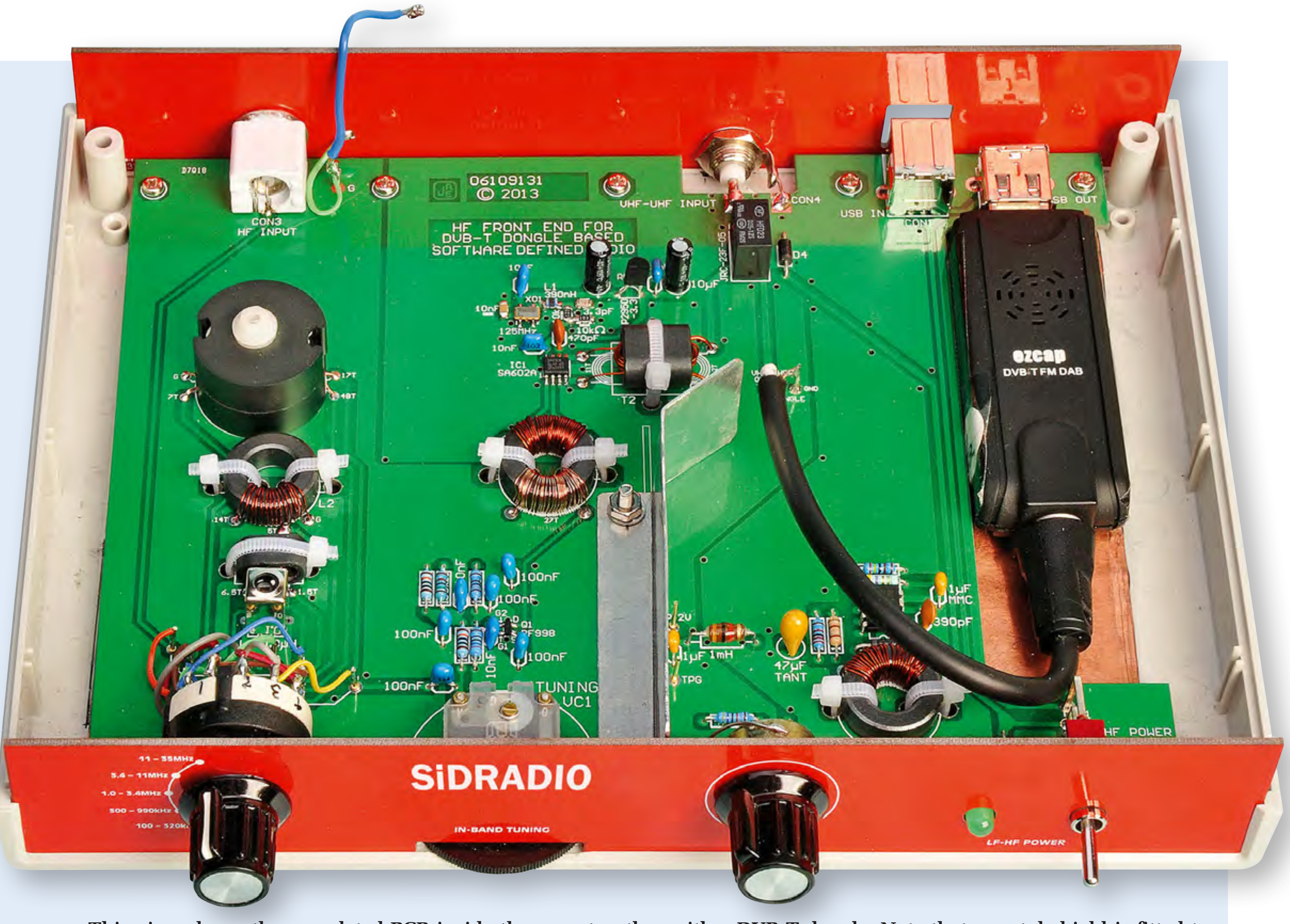
Fig.6: the parts layout and wiring diagram. Start with the SMD parts and make sure all polarised parts are correctly oriented.

(CON4) are mounted on a large PCB available from *EPE PCB Service*, coded 06109131 and measuring 197 × 156mm. This has a cut-out area at the righthand end to provide space for the DVB-T dongle and its input connector, in order to make an integrated assembly.

As shown in the photos, the PCB/DVB-T dongle assembly fits neatly into the low-profile ABS instrument case. Rotary bandswitch S2 mounts directly on the lefthand end of the front panel, while the VHF-UHF input connector (CON4) is mounted on the rear panel with its 'rear end' protruding into a second (small) cut-out in the PCB.

Fig.6 shows the parts layout on the PCB. There are eight SMD components in all: IC1 (SA612A), crystal oscillator module XO1, the 390nH inductor, a 3.3pF capacitor, a 10nF capacitor (alongside XO1), the two 10kΩ resistors and transistor Q1 (BF998). These parts should be installed first, starting with the five passive components and then Q1, XO1 and IC1.

You will need a fine-tipped soldering iron and a magnifier (preferably a magnifying lamp) to solder the SMD parts in. The trick is to carefully posi-



This view shows the completed PCB inside the case, together with a DVB-T dongle. Note that a metal shield is fitted to the PCB, while horizontal shields are fitted to the top and bottom of the case. The shields will be described next month.

tion each part on the PCB and solder just one lead to begin with, then check that the device is correctly aligned before soldering the remaining leads. If it's not correctly located, it's just a matter of re-melting the solder on the first lead and nudging the device into position.

Don't worry if you get solder bridges between IC1's pins when soldering it into position. These bridges can easily be removed using solder wick.

By the way, there are actually two versions of the BF998 MOSFET, both in the SOT-143 SMD 4-pin package – the standard BF998 and the BF998R with transposed (reversed) pin connections. Make sure you are supplied with the former and not the latter, because the PCB has been designed to suit the standard version and won't take the 'R' version. If you source the BF998 device from element14, it has the part number 1081286.

Both the SA612AD and the SA602AD mixer devices are in an SOIC-8 package and are pin compatible, so you can use either as IC1. They are made by NXP (formerly Philips) and are available from a number of suppliers, including element14. Whichever one you use, just make sure you fit it with the orientation shown in Fig.6 – ie, with its bevelled long edge towards transformer T1.

Crystal oscillator module XO1 has a footprint of just 4 × 3mm. This is a Fox 'XPRESSO' FXO-HC536-125 device, also available from element14.

Its orientation is also critical; it must go in with pin 1 (indicated by a tiny arrow or 'foxhead' symbol etched into one corner of the top sealing plate) at lower left as viewed in Fig.6 (you may need a good magnifying glass to locate that symbol).

Once these are in, install the leaded passive components, starting with the resistors and moving on to the capacitors and RF choke L6. Diodes D1 and D2 can then go in, making sure that you fit the correct diode in each position and with the correct orientation

Follow with 3.3V regulator REG1, then the MC34063 DC-DC converter controller (IC2). Make sure that these parts are fitted the right way around.

Power switch S1 is next, after which fit the USB input and output connectors (CON1 and CON2), the LF-HF input connector (CON3) and relay RLY1. Note that RLY1 is again a very small component, measuring just 12 × 7 × 10mm (L × W × H). A JRC-23F-05 relay from Futurlec was fitted to the prototype.

Next, you can fit the PCB terminal pins. There are 19 of these, 12 of which are located to the rear of S2 and one (TPG2) to the left of S2. Another TPG pin is located at upper left near CON3, while two further pins are located at centre right to terminate the RF output cable to the DVB-T dongle.

Main Features and Specifications

A compact 'RF front end' for a software defined radio using a laptop or desktop PC. It can incorporate virtually any of the DVB-T dongles used for SDR and couples the dongle to an up-converter for LF-HF reception, the latter effectively shifting LF-HF radio signals up by 125MHz into the VHF spectrum.

The front end also includes a signal-switching relay so when power is not applied to the LF-HF preselector and up-converter circuitry, the dongle's VHF-UHF signal input is switched directly to the VHF/UHF input (this avoids the need for cable swapping). All power for both the dongle and the front-end circuitry is derived from the USB port of the PC.

VHF/UHF input impedance: 75Ω unbalanced

Up-converter section conversion gain: approximately +10dB ±2dB over the input range 100kHz to 35MHz (corresponding output range = 125.1MHz to 180MHz)

LF-HF input impedance: 50Ω unbalanced

Preselector bands: Band 1 = 100-320kHz; Band 2 = 300kHz-1MHz; Band 3 = 1-3.4MHz; Band 4 = 3.4-11MHz; Band 5 = 11-35MHz

RF gain: variable from zero to about +20dB, over the range 100kHz to 35MHz.

Typical effective LF-HF sensitivity: Band 1 = 20-50µV; Band 2 = 18-50µV; Band 3 = 5-12µV; Band 4 = 1.5-4µV; Band 5 = 1-2µV

VHF/UHF output impedance: 75Ω unbalanced

Power supply: 5V DC from computer USB port

Current drain for VHF-UHF reception (ie, dongle only): less than 70mA

Current drain for LF-HF reception: less than 220mA

The remaining three pins are at lower centre of the PCB, two to the left of inductor L6 and one to the left of potentiometer VR1.

Fitting VC1

The next step is to fit tuning capacitor VC1. This must be spaced up from the PCB by 3.5mm, so that the tuning knob just clears the bottom of the case when the PCB is later fitted into it. Fig.7 shows the mounting details.

As can be seen, an M3 nut and small flat washers are used as a spacer on either side. In addition, the M2.5 × 4mm mounting screws supplied with the tuning capacitor have to be replaced with M2.5 × 6mm screws, to cope with the additional length required due to the spacers.

Make sure that VC1's three connection lugs at the rear are fed through their matching pads on the PCB when it is installed. Once VC1 is secured in position, these leads are then soldered to the pads on both sides of the PCB. The tuning knob can then be fastened to the shaft using one of the supplied M2.5 × 4mm screws.

Coils and transformers

The next step is to wind transformers T1 and T2 and also coils L1-L5. We'll deal with transformer T1 and coils L2 and L5 first, since they are all wound on identical toroidal ferrite cores, each with an outside diameter of 18mm and a depth of 6mm (eg, Jaycar LO-1230 or similar).

- **Transformer T1's** primary and secondary windings both consist of 27 turns of 0.3mm ECW (enamelled copper wire) wound closely on opposite sides of the toroid (they can be temporarily secured with tape). When both windings have been made, trim the leads to about 10mm and strip off 5mm of enamel from each end.

  The toroid assembly can then be mounted on the PCB and secured in place using two small nylon cable ties as shown in Fig.6. After that, it's just a matter of soldering its four leads to the relevant pads on the PCB.

- **Coil L2** consists of a single winding of 14 turns with a tap connection at four turns, again using 0.3mm ECW. After winding the first four turns, bring the wire straight out from the toroid, then double it back after about 12mm to form the tap connection and wind on the remaining 10 turns in the same direction as the first four.

  That done, trim the start and finish ends to about 10mm and strip 6mm of enamel from each end and from the

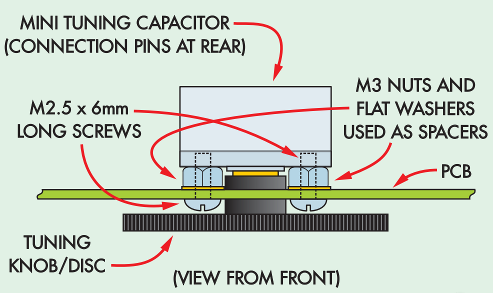
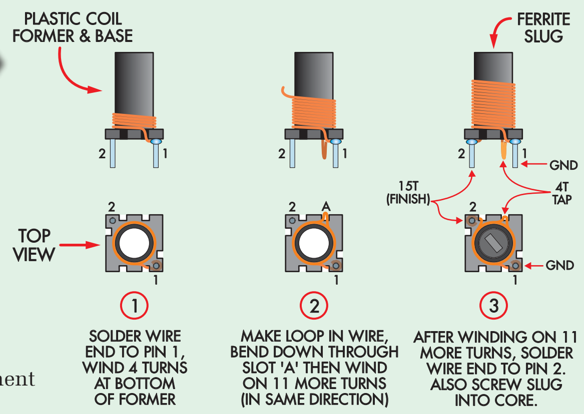


Fig.7: this diagram shows the mounting details for tuning capacitor VC1. It must be stood off the PCB by 3.5mm using M3 nuts and flat washers as spacers, so that its tuning wheel clears the bottom of the case.

Fig.8: the winding details for coil L4. It's wound using 0.3mm ECW on a small RF coil former, with a tap after four turns at position 'A'. Don't forget to fit the ferrite slug.



WINDING DETAILS FOR COIL L4

Software is crucial

The software needed to configure a DVB-T dongle and PC combination as an SDR consists of two main components: (1) a driver which allows the PC to communicate via the USB port with the Realtek RTL2832U (or similar) demodulator chip inside the dongle; and (2) application software to allow the PC to perform all the functions of an SDR in company with the SiDRADIO and its DVB-T dongle.

The driver must be installed first. The most popular driver for a DVB-T dongle with an RTL2832U demodulator chip (when used as an SDR) is the 'RTLSDR' driver (nearly all dongles use the RTL2832U). The website at **www.rtlsdr.org** provides lots of information on this.

Once the driver has been installed, the application software can be installed. The most popular application software is SDR#, available from **www.SDRSharp.com**

tap loop. The coil can then be fitted to the PCB, secured with nylon cable ties and the leads soldered.

- **Coil L5** can be tackled next. It simply consists of 26 turns of 0.3mm ECW, with no taps or other complications. As before, it's secured to the top of the PCB using two small cable ties.

- RF output transformer T2 is wound on a 14mm-long ferrite balun core (Jaycar LF-1220 or similar), with the winding wire passed up through one hole in the balun core and then back down through the other hole, and so on.

The secondary consists of just two turns of 0.8mm ECW and should be wound first. Then you can wind the primary, which consists of 11 turns of 0.25mm ECW. Note that the leads of the two windings emerge from opposite ends of the balun.

When you have finished both windings, trim the free wire ends to about 10mm and strip the enamel from each end. The completed balun can then be mounted on the PCB and its four wire leads soldered to their respective pads. Make sure that the balun is oriented with its 11-turn primary winding to the left and solder these wires on both sides of the PCB.

- **Coil L3** is wound on one of the smaller 6mm-long ferrite balun cores (Jaycar LF-1222 or similar). In this case, you need to wind on 6.5 turns of 0.3mm ECW with a 'loop tap' made after 1.5 turns from the start (ie, from the GND connection).

It's just a matter of winding on the first 1.5 turns, then bringing the wire out and doubling it back after about 12mm to form the tap, then winding on the remaining five turns – see Fig.6.

- **Coil L4** (band 5) is close-wound on a small RF coil former that's fitted with a ferrite tuning slug and housed in a shield can (Jaycar LF-1227 or similar). Although this coil only has 15 turns of 0.3mm ECW with a loop tap, it's a bit fiddly to wind because of the former's small size and because the former has only two termination pins.

Fig.8 shows the winding details for L4. The 'loop tap' is formed just after four turns from the start/GND end (pin 1) and is fed down through one of the small slots (A) in the former's base, so that it can subsequently be fed through its matching hole in the PCB. Again, make this 'loop tap' about 12mm long, then wind on the remaining 11 turns and terminate the wire on pin 2.

That done, screw the supplied ferrite slug into the former, along with the small piece of rubber thread supplied to act as a 'hold tight'. You should then scrape the insulating enamel from the 'tap loop' so that it's ready for soldering.

The completed coil assembly can now be mounted on the PCB (just below coil L3). Orient it as shown on Fig.6, so that the two pins and the 'tap loop' each go through their matching PCB holes (ie, pin 1 GND at bottom right, 4T tap at top). Once it's in place, solder the three connections underneath the PCB, making sure that you get a good solder joint to both of the tap loop wires.

The next step is to gently screw down the ferrite slug inside L4 using a nylon alignment tool until it just touches the surface of the PCB. That done, slip the metal shield can over the completed coil former, until its two attachment lugs pass down through the holes provided on each side. These are then soldered to their pads on the

Capacitor Codes

Value	µF Value	IEC Code	EIA Code
1µF	1µF	1u0	105
220nF	0.22µF	220n	224
100nF	0.1µF	100n	104
10nF	0.01µF	10n	103
470pF	NA	470p	471
390pF	NA	390p	391
3.3pF	NA	3p3	3.3

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	1	150kΩ	brown green yellow brown	brown green black orange brown
❏	2	100kΩ	brown black yellow brown	brown black black orange brown
❏	1	47kΩ	yellow violet orange brown	yellow violet black red brown
❏	2	22kΩ	red red orange brown	red red black red brown
❏	2	10kΩ	brown black orange brown	brown black black red brown
❏	1	2.4kΩ	red yellow red brown	red yellow black brown brown
❏	1	1.8kΩ	brown grey red brown	brown grey black brown brown
❏	1	390Ω	orange white brown brown	orange white black black brown
❏	1	360Ω	orange blue brown brown	orange blue black black brown
❏	1	180Ω	brown grey brown brown	brown grey black black brown
❏	1	4.7Ω	yellow violet gold brown	yellow violet black silver brown

Parts List for SiDRADIO

1 double-sided PCB, available from the *EPE PCB Service*, code 06109131, 197 × 156mm
1 set of front and rear PCB panels, available from the *EPE PCB Service*, code 06109132 and 06109133 (200 × 30mm)
1 low profile ABS instrument case, 225 × 165 × 40mm
1 DVB-T dongle (using an RTL2832U decoder chip and either the R820T, E4000 or FC0013 tuner chips)
1 short length of 75Ω coaxial cable, with plug to suit RF input of dongle
1 HCMOS 3.3V crystal oscillator module, 125MHz (Fox Electronics FXO-HC536-125 or similar, element14 2058072) (XO1)
1 SPDT 5V mini DIP relay, JRC-23F-05 or similar (Futurlec) (RLY1)
1 SPDT PCB-mount vertical acting toggle switch (S1)
1 2-pole 5/6-position rotary switch (S2)
1 USB type B socket, horizontal PCB-mount (CON1)
1 USB type A socket, horizontal PCB-mount (CON2)
1 BNC socket, PCB mount (CON3)
1 PAL (Belling-Lee) socket, panel-mount (CON4)
2 instrument knobs, 20mm diameter × 18mm deep
3 toroidal ferrite cores, 18mm diameter × 6mm deep (Jaycar LO-1230 or similar)
1 6mm-long ferrite balun core (Jaycar LF-1222 or similar)
1 14mm-long ferrite balun core (Jaycar LF-1220 or similar)
8 small Nylon cable ties
1 mini RF coil former with slug and shield can (Jaycar LF-1227 or similar)
1 pair of ferrite pot core halves with bobbin (Jaycar LF-1060 + LF1062 or similar)
1 50kΩ linear pot, 16mm (VR1)
1 10 – 120pF miniature PCB-mount tuning capacitor with knob and mounting screws (VC1) (Jaycar RV-5728 or similar)
1 M3 × 25mm nylon machine screw
1 M3 nylon nut
2 M3 flat nylon washers
19 PCB pins, 1mm diameter
1 1mH axial RF choke/inductor (L6)
1 390nH SMD inductor, 0805 (L7)
2 M2.5 × 6mm machine screws
10 6mm-long No.4 self-tapping screws
1 M3 × 6mm machine screw
1 M3 spring lockwasher
3 M3 nuts
2 M3 flat washers
1 90 × 36 × 0.8mm aluminium sheet or tinplate (to make vertical shield)
1 rectangular piece of blank PCB, 195 × 150mm (for top horizontal shield)
1 196 × 134 × 0.25mm copper foil or tinplate (for bottom horizontal shield)
1 200mm-length 0.25mm-dia, ECW
1 1m-length 0.3mm-dia. ECW
1 100mm-length 0.8mm-dia. ECW
Tinned copper wire, hook-up wire, etc

Semiconductors
1 SA612AD/01 or SA602AD/01 double balanced mixer (IC1) (element14 2212081 or 2212077)
1 MC34063 DC-DC converter (IC2)
1 BF998 dual-gate VHF MOSFET (Q1) (element14 1081286)
1 LP2950-3.3 or LM2936-3.3 LDO regulator (REG1)
1 5mm green LED (LED1)
1 1N5819 Schottky diode (D1)
1 1N4004 silicon diode (D2)

Capacitors
1 47µF 10V RB electrolytic
1 47µF 16V tantalum
1 10µF 16V RB electrolytic
2 1µF MMC
1 220nF MMC
5 100nF MMC
5 10nF MMC
1 10nF SMD ceramic (1206)
1 470pF disc ceramic
1 390pF disc ceramic
1 3.3pF C0G/NP0 SMD ceramic (1206)

Resistors (0.25W, 1%)
1 150kΩ
2 100kΩ
1 47kΩ
2 22kΩ
2 10kΩ SMD (0805)
1 2.4kΩ
1 1.8kΩ
1 390Ω
1 360Ω
1 180Ω
1 4.7Ω 0.5W

See next issue for advice on sourcing hard-to-find parts

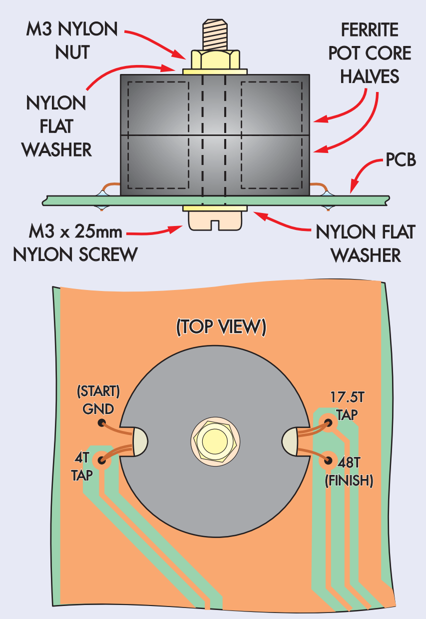


Fig.9: coil L1 is wound on the bobbin of a 2-part ferrite pot core (see text) and secured to the PCB using an M3 × 25mm nylon screw, washers and nut.

underside of the PCB to secure the can in place.

Winding coil L1

L1, the remaining coil (Fig.9) is wound on the bobbin of a 2-section ferrite pot core assembly measuring 25mm in diameter and 16.5mm high (Jaycar LF-1060 + LF1062 or similar).

This coil is wound in a conventional fashion directly on the bobbin and consists of 48 turns of 0.3mm ECW with two tapping loops. The winding procedure is as follows.

First, anchor the ‘start’ end of the wire to one side of the bobbin using cellulose tape. That done, close-wind four turns onto the bobbin, then bring out a loop of wire to form the antenna ‘tap’ via the same slot in the bobbin’s side that was used for the ‘start’ lead. Anchor this loop tap to the side of the bobbin with another small piece of cellulose tape, then close-wind on 13.5 more turns in the same direction as the first four turns.

After winding on these extra turns, bring out another tap loop through the slot in the opposite side of the bobbin (ie, opposite the ‘start’ and ‘4T tap’ wires). Anchor this loop to the outside of the bobbin using cellulose tape, then wind on a further 13 turns to fill this first winding layer.

Next, apply a narrow strip (9-10mm wide) of cellulose tape over this layer

Performance limitations

While the combination of a DVB-T dongle with an up-converter and an HF preamp and preselector – as provided by the SiDRADIO – can provide many of the operating features of a high-performance communications receiver, it's unrealistic to expect exactly the same performance. The high cost of communications receivers is the price you pay for superb sensitivity and selectivity, FM quieting, excellent image rejection and so on. You are not going to get that sort of performance from a set-up costing a great deal less.

Apart from anything else, most DVB-T dongles are in a plastic case that provides no shielding against the ingress of strong VHF signals like those from FM stations and DAB+ stations – or from the PC you're using with the SDR front end. So even though we have taken a great deal of care to provide shielding for both the dongle and the rest of the front end circuitry, you're still likely to find spurious 'breakthrough' signals in that part of the VHF spectrum into which the up-converter shifts the incoming HF signals. Having said that, the shielding does significantly reduce breakthrough compared to an unshielded dongle.

Another reason why you'll tend to find spurious signals is that the simple input tuning circuitry of the preselector section is inevitably rather modest in terms of selectivity. So although the new unit does provide rejection of interfering signals, it's still not in the same league as a high-performance HF communications receiver.

In spite of that, it's surprising what results you can get out of this new all-in-one SDR interface, particularly if you team it up with a long-wire HF antenna or an active indoor HF loop antenna with its own low-Q tuning circuit.

to hold it all in place, then continue winding in the same direction to produce a second layer of 18 turns.

When the last turn has been wound on, bring the wire end out through the same bobbin slot as the '17.5T tapping loop' and cut it off about 10mm from the bobbin. This lead becomes the 48-turn 'top' of coil L1. Another narrow strip of cellulose tape is then placed over the second layer to hold everything in place.

With the windings completed, the next step is to scrape off about 5mm of enamel insulation from the ends of all four coil connections. That done, place the bobbin inside one half of the ferrite pot core and fit the assembly to the PCB as shown in Fig.9, with each wire or loop connection fed into its matching PCB hole.

The top half of the pot core is then fitted in position and the entire coil assembly secured to the PCB using an M3 × 25mm nylon machine screw, two nylon flat washers and an M3 nylon nut. Note that the screw should be passed up through the PCB from underneath, as shown in Fig.9.

Finally, solder the various leads running from L1 to the PCB pads on both sides of the board.

Completing the PCB assembly

The PCB assembly can now be completed (apart from its central shield) by fitting VR1 and LED1. Before fitting VR1, cut its shaft to a length of about 9mm and remove any burrs. VR1 can then be soldered into position, after which a short length of tinned copper wire is used to connect the pot's metal shield can to the earth copper of the PCB, via earth terminal pin TPG1.

Note that you may have to scrape away the passivation from a small area of the pot's metal shield and apply some flux in order to achieve a good solder joint. You will also need a really hot soldering iron.

LED1 is mounted vertically with 20mm lead lengths (use a cardboard spacer). Be sure to orient it with its anode lead (A) to the right. Once it's in place, bend its leads forward by 90° about 8mm above the PCB so that it will later protrude through its matching hole in the front panel.

The next step is to make the central shield for the PCB plus top and bottom horizontal shields to ensure good performance. We'll detail these shields and complete the construction in Part 2 next month.

Power politics

TechnoTalk

Mark Nelson

AC or DC, which way to go? It's a serious question that is exercising the minds of the people who plan the provision of electricity generation and distribution for the future. Mark Nelson examines the issues at stake.

CHANCES ARE THAT THE MAINS supply to your house is AC – alternating current. If your only supply is a wind generator or an array of solar panels, then you may be getting by with DC, but you will be in a minority. That's not the case in other parts of the world, however. In North America for instance, there are nearly a million homes and businesses not on the grid, mostly running on DC power. The same applies to motor homes and caravans.

Today's supply is usually AC, but only for historical reasons that will almost certainly hold no validity in 50 years hence. Rational people are questioning why we need AC even now, let alone the future. Electric heating would work equally well on DC, as would lighting (if we used LED bulbs). Computers, televisions, radio receivers and all manner of other electronic devices all require low-voltage DC, incurring a conversion loss from the 230V AC mains that only adds to energy usage. Energy loss also occurs in converting the DC produced by photovoltaic systems to AC, and then in many cases back to DC. If there is a mass movement towards electric cars, the conversion losses will mount even higher.

So, which devices or products does this leave that must have AC? Mainly washing machine motors, refrigerators, vacuum cleaners, central heating pumps and clocks, all of which happen to use AC power (but do not need to if redesigned to operate on DC).

Historical interlude

Some readers will remember that you could still encounter direct current (DC) power mains right up until the mid-1950s in some towns. Most electricity generating stations were originally municipally owned, producing power for operating the electric trams and trolleybuses, also for arc lamps used for street lighting. These devices were all operated by DC, meaning that the surplus energy supplied to homes, offices and factories was also DC. Subsequently, alternating current (AC) appeared on the scene and became the standard. The current (sorry!) question is whether AC is the best kind of electric power.

Battle of the currents

A new 'battle of the currents' is about to break out, according to the 'smart grid' experts of the American Institute of Electrical and Electronic Engineers (IEEE). Advances in technology and the increase of devices that can generate or operate on DC power are again raising the debate over AC vs. DC power, they say. Eliminating conversion from DC to AC and vice versa can greatly improve the efficiency of both the grid and the devices that can operate in a DC mode. Solar photovoltaic panels, batteries and fuel cells generate or store DC power, and residential, commercial and industrial facilities are projected to increase DC electrical loads that do not require first converting to AC.

Of course, we won't abandon AC overnight, and in developed regions of the world where the AC power grid is well established, it may not be feasible to change large portions of the existing grid to DC. However, certain aspects of the grid, such as distribution primaries and secondaries may still be candidates for a DC revolution. Regions of the world where electric infrastructure is still developing may be able to adopt the latest innovations in DC energy production, transportation and end-use technologies.

Renewables will be the primary source of electricity there, and the vast majority of these are DC-based, as are the batteries that will store that power. Even in more developed countries, pressure to reduce our dependence on fossil fuels will encourage the use of renewably generated power, all meaning that the market for high-quality DC-based systems will grow rapidly over the next decade, as standards are created that allow anyone's equipment to work with anyone else's equipment and the cost of generation (photovoltaic cells, wind farms and wave power) continues to drop.

Economic advantage

Semiconductor specialists Infineon Technologies, a spin-off of electrical giant Siemens, sums up the reasons for change, stating there are many advantages to using direct rather than alternating current. For example, when using direct current there are 5 to 7 per cent less losses in power grids and electric devices. Direct current also makes it possible to feed electric energy from regenerative sources into power grids and energy storage devices more efficiently, thereby improving grid stability.

Circuit breaker solutions

Admittedly, until now it has not been possible to fully explore the potentials of direct current because of a lack of efficient and cost-effective circuit breaker technologies. The electromechanical circuit breakers available today cause a risk of arcing when switching direct current and voltages, and are slow, heavy and expensive. To eliminate this shortcoming, the German Federal Ministry of Education and Research is funding Infineon to investigate the foundations of an innovative semiconductor-based and completely electronic circuit breaker for DC power grids and applications. The circuit breaker should be able to switch direct current on and off as quickly and safely as possible, at voltages up to 1500V.

Save printer ink

Switching subjects, but remaining eco-minded, I think I can safely say that we all enjoy saving money. If you print a lot of documents and want to economise, normally you have to enter 'draft' mode in order to save ink (for inkjet printers) or toner powder (for laser machines). But there's another way: print your documents in a font specially designed to print more sustainably. It's a clever idea, but not exactly new.

Nevertheless, the latest 'eco-font' is claimed to use a third less ink than standard fonts and one quarter less than other eco fonts, without losing legibility. Sponsored by the stationery company Ryman, the new font could save more than 490 million ink cartridges and nearly 15 million barrels of oil, equivalent to 6.5m tonnes of CO_2 emissions a year if everyone used the font when printing.

So why not take a look? You can download the font for free at: **www.rymaneco.co.uk**

EPE EXCLUSIVE

Win a Microchip MGC3130 Hillstar 3D Gesture Development Kit

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a MGC3130 Hillstar Development Kit (DM160218), for 3D gesturing systems. The kit provides designers with an easy step-by-step approach to developing 3D gesturing systems with Microchip's MGC3130 and electrodes that meet their specific space requirements. The MGC3130 is the world's first single-chip 3D gesture/free space position tracking solution. The MGC3130 Hillstar Development Kit is a complete reference system consisting of an MGC3130 module and one example 4-Layer reference electrode with 95 × 60mm sensitive area. With several additional reference electrode designs, the Aurea Graphical User Interface Software, and an I²C-to-USB bridge module, the kit enables easy design of the MGC3130 into several different form factors.

The GestIC Technology enabled with the MGC3130 serves a wide range of applications in computing, such as laptops, keyboards, input devices; in lighting applications, including light switches and controls; in consumer electronics, such as audio docks, printers and copiers; and automotive markets for automotive interior controls, among others.

The MGC3130 Hillstar Development Kit enables customers to integrate an advanced 3D hand position and gesturing user interface into virtually any electronic product using a modular approach with complete documentation, reference layouts, hardware and a software GUI.

WORTH $180.00 (approx. £109.00) EACH

JUNE 2014 ISSUE WINNERS

Malcolm Priestley, who works at Selex-es
Anthony Hubbard, who works at TUV-SUD Product Service Ltd
David Widdup, who works at IMA LTD

They all won a Microstick for the 3V PIC24F K-Series valued at £21.00 each

HOW TO ENTER

For the chance to win MGC3130 Hillstar 3D Gesture Development Kit please visit:
http://www.microchip-comps.com/epe-hilstar and enter your details in the online entry form.

CLOSING DATE

The closing date for this offer is 31 October 2014

If you can't afford a high-performance amplifier and loudspeakers, you can still have the best possible Hi-Fi sound, with this headphone amplifier and a set of high-quality headphones.

By NICHOLAS VINEN

Hi-Fi Stereo Headphone Amplifier – Part 1

YES, WE KNOW that some of the very high quality amplifiers we have covered in *EPE* are 'over the top' for many people, especially those living in small homes and those who have to worry about sound levels annoying their neighbours.

But why not listen via a good pair of headphones? Spend a few minutes looking around the Internet and you will find all manner of Hi-Fi headphone amplifiers that claim to have top-notch performance. In most cases, there is little or no performance data to prove it. Before spending upwards of £1000 on a headphone amplifier we'd want to know just how good it is!

Our new headphone amplifier has a performance virtually the same as our best designs. Its distortion at 100mW is lower than that from even the best CD and Blu-ray players. So essentially what you hear is what is recorded on the CD – no more and no less.

This project is not intended to replace *portable* designs, since those

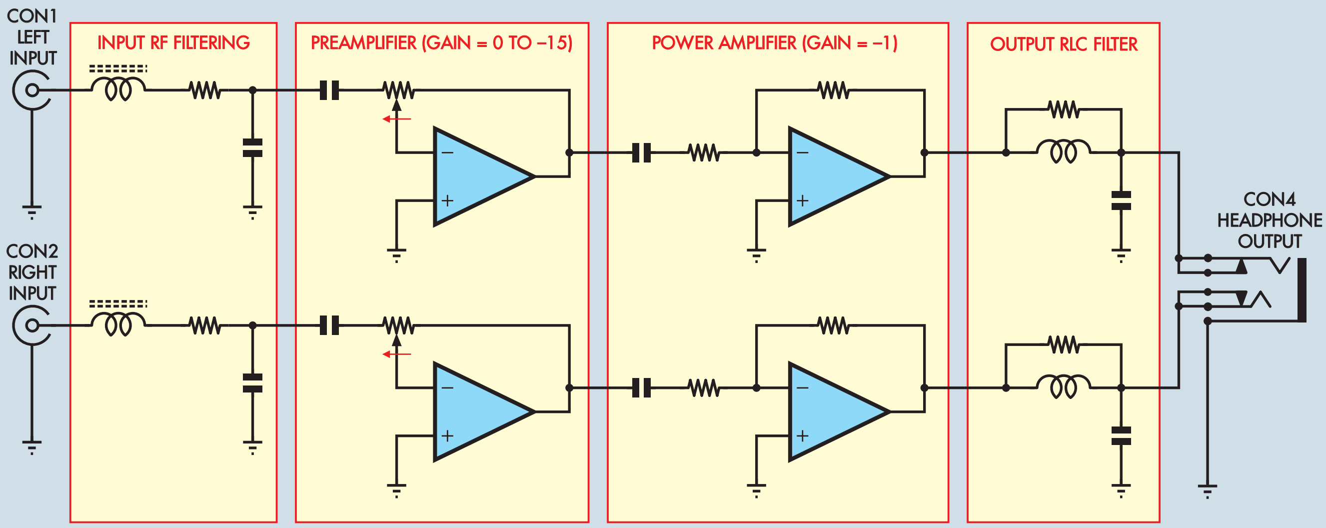


Fig.1: this block diagram shows the basic arrangement of the *Headphone Amplifier*. It incorporates RF filtering, a stereo preamplifier, stereo amplifier, output isolation filters and a regulated power supply.

need to be small, light and battery-powered.

Speaker driver too

This new headphone amplifier will also drive 8Ω loudspeakers and has a music power of 4.25W for both channels driven. This is more than adequate if you have reasonably efficient loudspeakers in your study, office or bedroom.

It is housed in a half-size 1U steel case just 210mm wide, 49mm high and 125mm deep and is powered by an AC plugpack (no 230VAC mains wiring). The interior of the case is filled by the PCB which accommodates all the components. There is no other wiring to do; just assemble the PCB, fit it into the case and you're finished.

Circuit features

Fig.1 shows the block diagram of the unit, while Fig.2 shows the complete circuit. It looks huge, doesn't it? That's partly because it shows both channels. It can be split into two sections, with the preamplifiers and power supply on the lefthand side and the power amplifiers on the righthand side.

The preamplifier for each channel is based on three op amps, so three LM833 dual op amps are used. The preamp configuration is a classic Baxandall design. The preamplifier is inverting and has a gain range from zero to –15.

The reason for such a wide range in gain is that we have to provide for a large variety of headphone impedances and sensitivities. 8Ω headphones require a much lower voltage swing for the same power compared to 600Ω phones. Driving 8Ω headphones from a CD player (typically 2V RMS) may require a gain of 0.25 or less, while using 600Ω phones with a line level signal (0.775V RMS or sometimes less) could require a gain of several times.

The Baxandall preamplifier circuit has the advantage that it varies its gain according to the setting of potentiometer VR1. As a result, the residual noise level is kept low at the low gain settings most commonly required. Like a traditional preamplifier, its gain can go all the way down to zero and up to some fixed number, in this case, 15.

Another advantage of this circuit is its log-like gain curve from a linear potentiometer, which generally have superior tracking compared to log pots. All but the most expensive 'log' law potentiometers actually use a dual linear taper and so they don't really have an accurate log response anyway.

The two power amplifiers on the righthand side of the circuit are loosely based on a 20W class-A amplifier, but with smaller output transistors and heatsinks. The power amplifiers invert the signal again, so the unit's outputs and inputs are in-phase. Since

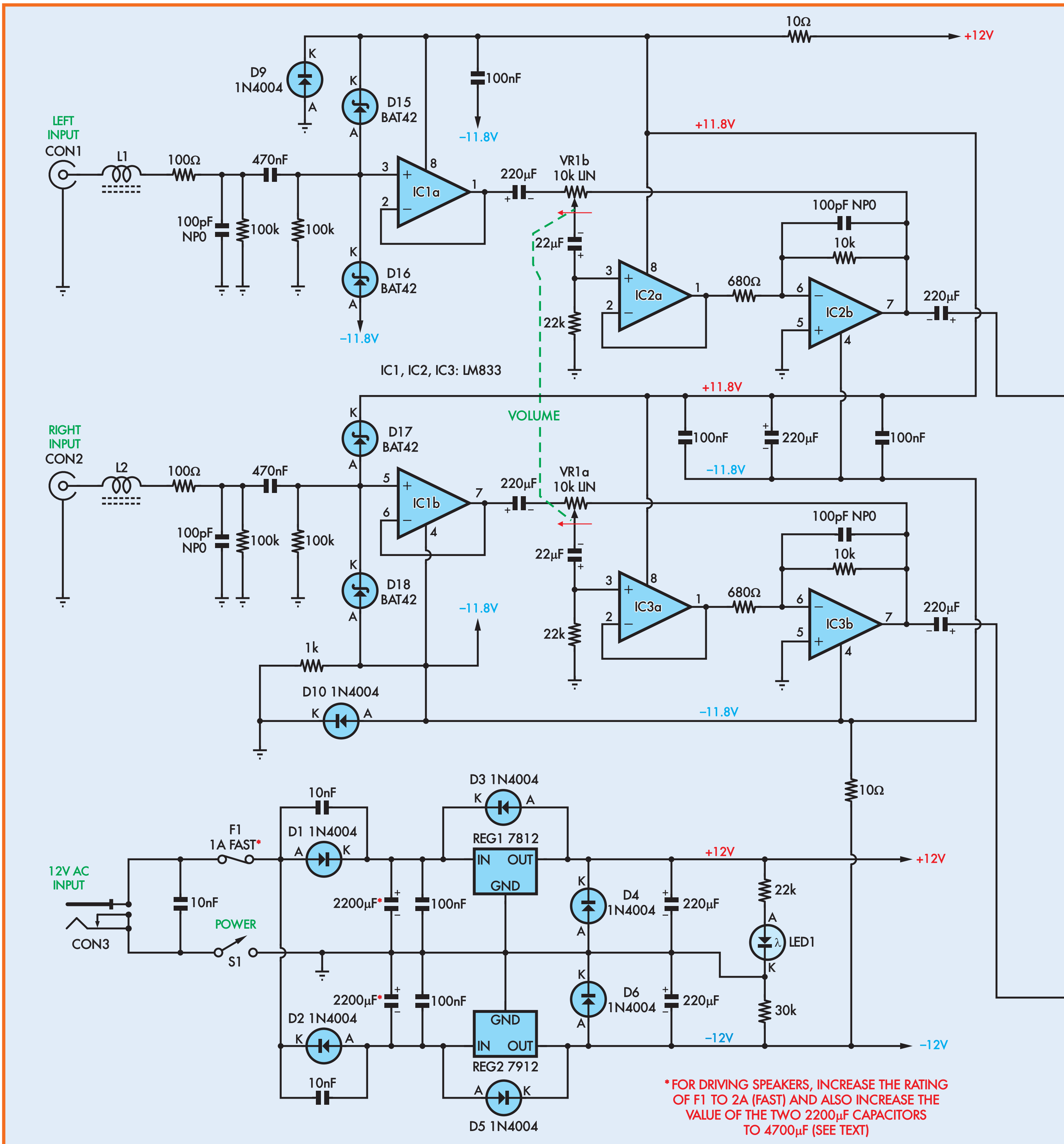
Features and Specifications

Main Features

- Suits 8Ω – 600Ω headphones and ear-buds
- Very low distortion and noise
- Plugpack-powered (no mains wiring)
- Short-circuit protected
- Can also drive efficient 8Ω loudspeakers

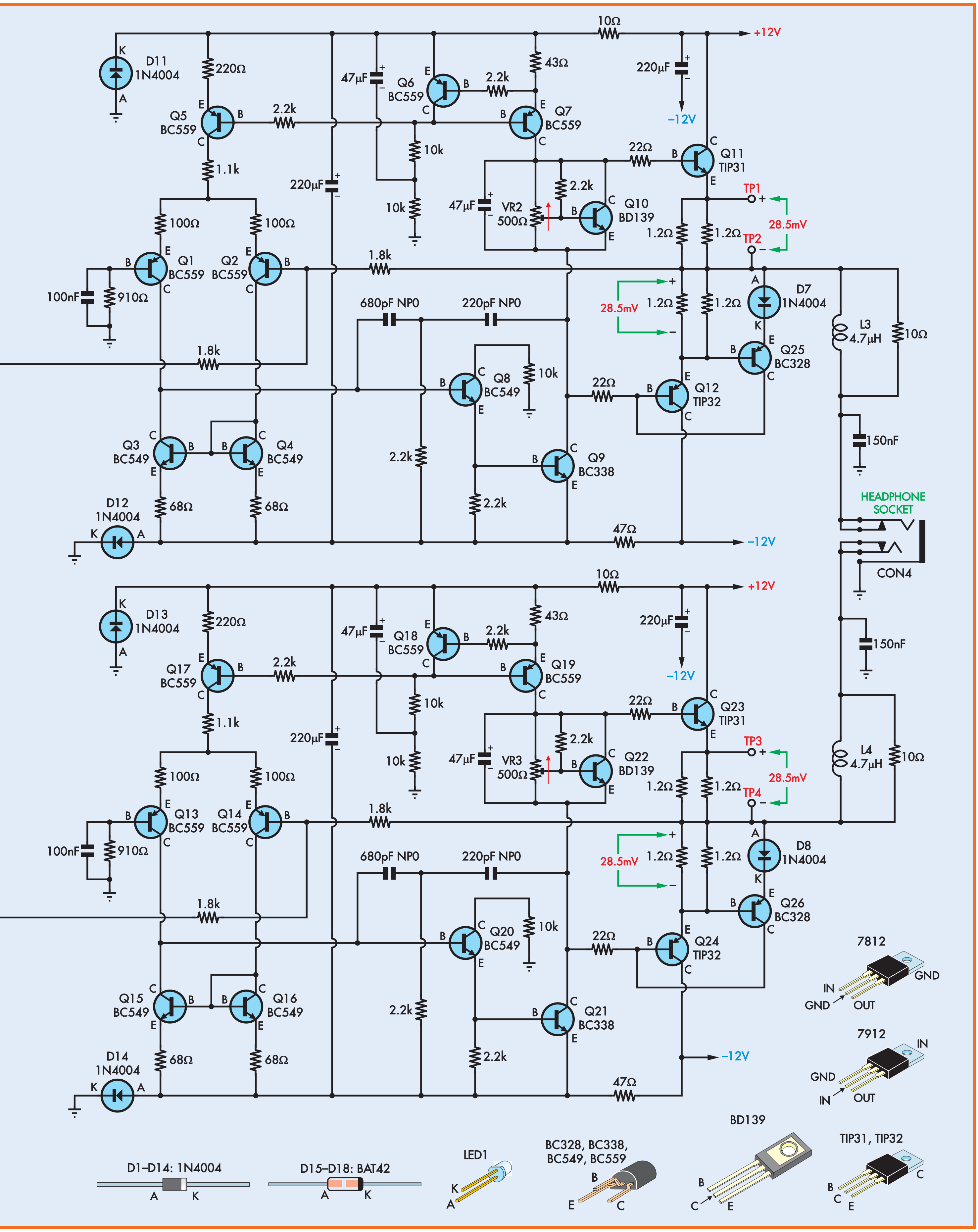
Specifications (Figs.3-7)

Rated power: 100mW (8-100Ω), 25mW (600Ω)
THD: 0.0006% @ 1kHz; 20Hz-22kHz bandwidth
Signal-to-noise ratio: –113dB unweighted; 20Hz-22kHz
Frequency response: ±0.15dB, 20Hz-20kHz
Channel separation: –73dB @ 1kHz
Maximum power: 4.25W (8Ω), 3W (16Ω), 1.5W (32Ω), 800mW (60Ω), 80mW (600Ω)
Class-A power: 18mW (8Ω), 36mW (16Ω), 72mW (32Ω), 80mW (600Ω)
Music power: 4.25W into 8Ω, both channels driven (see text)



Hi-Fi STEREO HEADPHONE AMPLIFIER

Fig.2: the complete circuit of the *Hi-Fi Stereo Headphone Amplifier*. The stereo preamplifier section is at upper left and is based on three low-noise dual op amps (IC1-IC3). This stage provides a variable gain of 0-15 depending on the setting of VR1 which functions as the volume control. The two identical power amplifiers are shown at right and these drive the headphones via RLC filters (for stability) and a 6.35mm jack socket. The linear regulated power supply is at lower left and this derives regulated ±12V rails from a 12V AC plugpack.



+12V
10Ω
D11
1N4004
K
A
220Ω
47µF
Q6
BC559
2.2k
43Ω
220µF
–12V
Q5
BC559
Q7
BC559
10k
1.1k
220µF
22Ω
Q11
TIP31
2.2k
TP1
10k
47µF
VR2
500Ω
Q10
BD139
28.5mV
1.2Ω
TP2
100Ω
100Ω
Q1
BC559
Q2
BC559
1.8k
D7
1N4004
100nF
910Ω
680pF NP0
220pF NP0
28.5mV
1.2Ω
1.2Ω
L3
4.7µH
10Ω
1.8k
Q25
BC328
Q8
BC549
10k
22Ω
Q12
TIP32
Q3
BC549
Q4
BC549
150nF
2.2k
Q9
BC338
2.2k
HEADPHONE
SOCKET
D12
1N4004
68Ω
68Ω
47Ω
–12V
CON4
D13
1N4004
Q18
BC559
Q17
BC559
Q19
BC559
150nF
Q23
TIP31
TP3
VR3
500Ω
Q22
BD139
TP4
L4
4.7µH
Q13
BC559
Q14
BC559
D8
1N4004
Q26
BC328
Q20
BC549
Q24
TIP32
7812
IN
GND
OUT
Q15
BC549
Q16
BC549
Q21
BC338
7912
D14
1N4004
BD139
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D15–D18: BAT42
LED1
BC328, BC338,
BC549, BC559
TIP31, TIP32

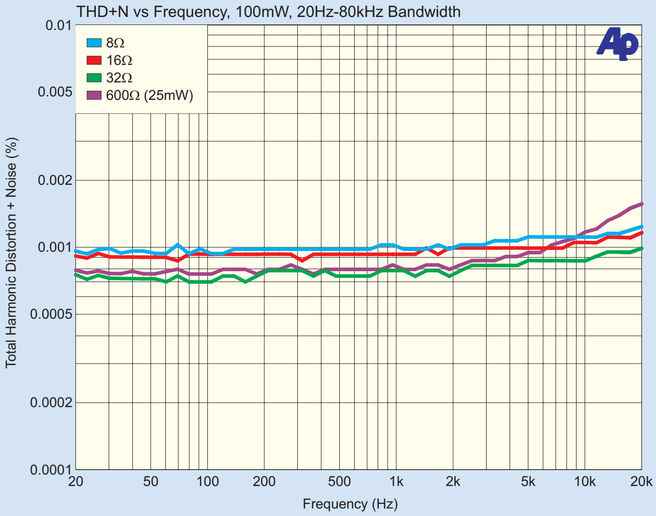


Fig.3: total harmonic noise and distortion (THD+N) vs frequency for four typical load impedances. The slight increase in distortion above 3kHz for a 600Ω load is due to slew rate limiting.

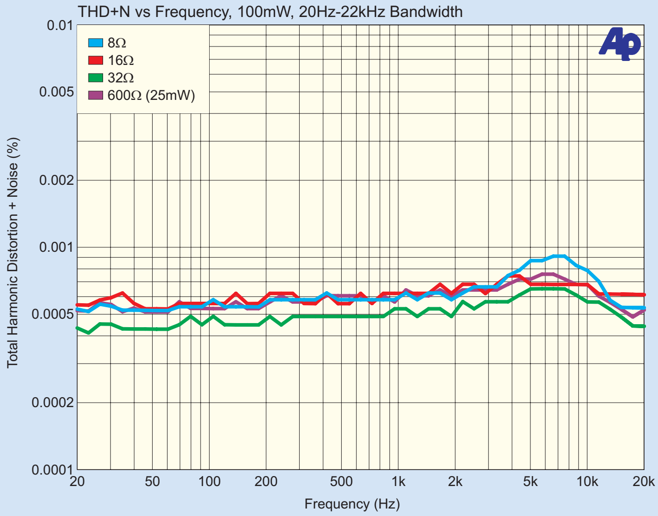


Fig.4: THD+N but with a 22kHz upper bandwidth limit. This gives more accurate figures for low frequencies but also eliminates high-frequency signal harmonics, hence the artificial drop in distortion above 7kHz.

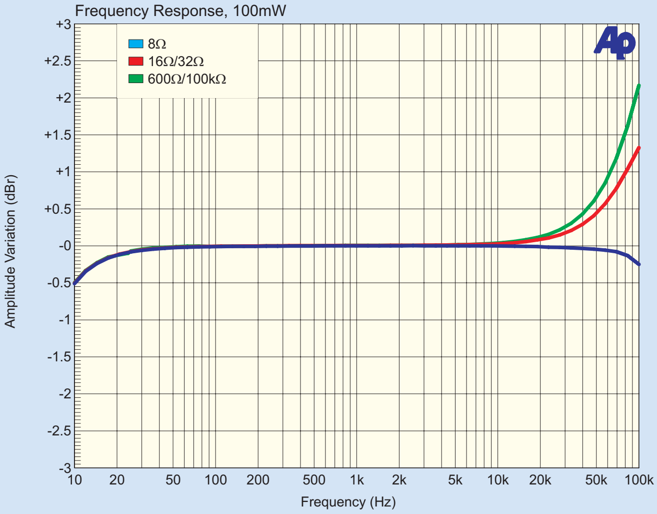


Fig.5: the frequency response for typical loads. The low-end –3dB point is around 3Hz, while the high-frequency response is defined by the output filter and so varies with load impedance. This results in a slight treble boost for loads of 16Ω and above.

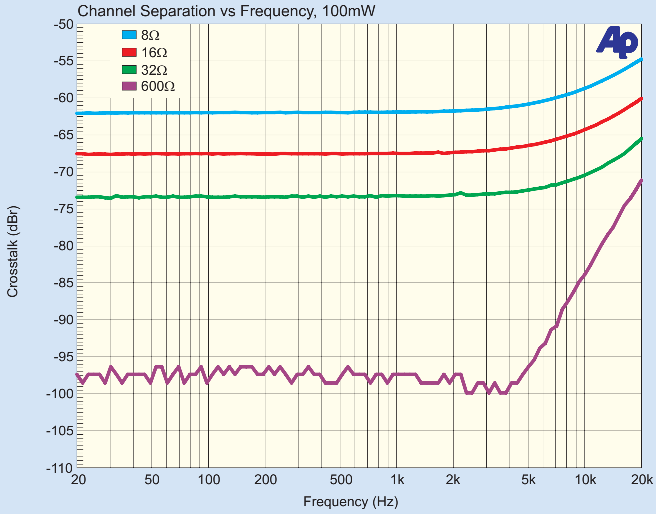


Fig.6: channel separation versus frequency. Most of the crosstalk that occurs is due to shared ground paths; it is resistive and so constant with frequency but varies with load impedance. Above 5kHz, some additional capacitive and inductive crosstalk is apparent.

there is so much gain available in the preamps, the power amplifiers operate at unity gain (ie, –1). This improves the noise performance and maximises the feedback factor, keeping distortion exceedingly low – even with run-of-the-mill output transistors.

Because the headphone connector is a jack socket, the outputs can be briefly short circuited if the plug is inserted or removed during operation. As a result, the design incorporates short-circuit protection to prevent any damage.

Our noise and distortion figures are quoted at 100mW for 8-32Ω and 25mW for 600Ω. With efficient headphones, this is enough to generate very high sound levels. For most headphones, a typical listening level is 0.5-5mW.

Common-mode distortion

By lowering the gain, we get a higher feedback factor (which is good) but we also increase the possibility of common-mode distortion. This can reduce the effectiveness of a high feedback factor so that the distortion reduction (due to the feedback) is not as much as would otherwise be the case.

While the differential input voltage (ie, the voltage between the two inputs) of an amplifier operating in closed-loop mode is very small, both input voltages can still have large swings, especially when the amplifier is being driven hard. This is the 'common-mode' signal, ie, the signal common to both inputs.

For a non-inverting amplifier, the common-mode voltage is the output voltage swing divided by the closed-loop gain. So with unity gain, the common-mode signal amplitude is the same as the output signal amplitude,

which for our amplifier can be nearly 20V peak-to-peak. Typically, if the common-mode signal exceeds 1-2V RMS, common-mode distortion can become the dominant distortion mechanism, marring its performance.

This is due to 'Early effect' in the input transistors (named after James Early of Fairchild Semiconductor). This is caused by the effective width of the transistor base junction varying with its collector-base voltage (see **http://en.wikipedia.org/wiki/Early_effect**).

If the common-mode voltage is large enough, the result is modulation of the input transistors' beta and this reduces the overall linearity of the amplifier. These non-linearities cannot be corrected by negative feedback since they occur in the input stage.

The solution is to use an inverting amplifier, as we have in this case. Its non-inverting input is connected to ground and so the inverting input is held at 'virtual ground' too, regardless of the output voltage. This configuration has so little common-mode voltage that it can't suffer from common-mode distortion. To make a power amplifier inverting, we rearrange the feedback network in the same manner as we would with an op amp. In fact, common-mode distortion in op amps can be reduced using the same method.

The main disadvantage of the inverting configuration is that the input impedance is low, as determined by the resistor from the signal source to the inverting input. For good noise performance, its value must be low (minimising its Johnson-Nyquist thermal noise). In this case, the preamplifiers provide the amplifiers with a low source impedance, so it isn't a problem.

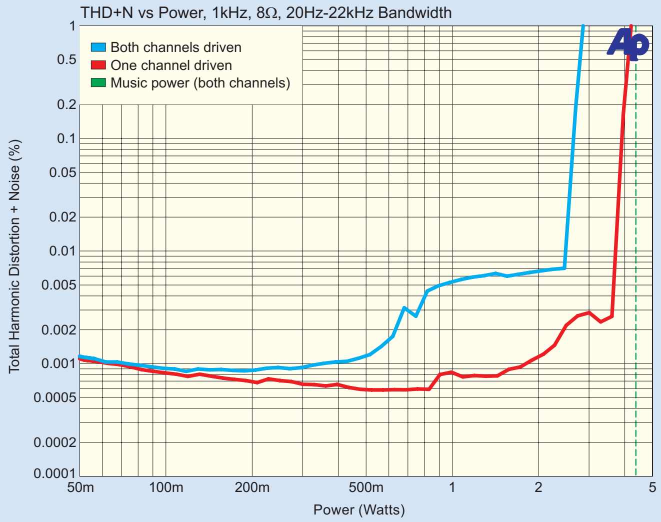
No driver transistors

This design uses 2-pole frequency compensation. As a result, the headphone amplifier has particularly low distortion at high frequencies.

In this amplifier, the two output transistors are driven directly from the voltage amplification stage, with no driver transistors in between. In this case, the output current is quite small due to the relatively low power, so we can get away without the driver stage as long as the output transistors have a good beta figure.

Here, we are using readily available TIP31 (NPN) and TIP32 (PNP) transistors, rated at 3A, 40W each; more than enough for our needs. They have an excellent beta for a power transistor, around 200 for 100mA at 25°C.

Fig.7: total harmonic distortion and noise versus power with the larger filter capacitors and a 2A plugpack. Music power is 4.25W (both channels driven) but continuous output power is limited by the power supply.



How it works

Let's start with the preamp stages and since both channels are identical, we will just describe the left channel. Any RF signals picked up by the input leads are attenuated by a low-pass filter consisting of a ferrite bead, a 100Ω resistor and a 100pF capacitor. The ferrite bead acts like an inductor to block RF. The signal is then coupled via a 470nF capacitor to pin 3 of op amp IC1a which is configured as a voltage follower. This provides a low source impedance to the preamp gain stages comprising IC2a and IC2b.

IC1a's output is fed to the following stage via a 220µF electrolytic capacitor. This large value ensures good bass response and avoids any distortion that may arise from the typical non-linearity of an electrolytic capacitor.

The signal passes to the non-inverting input of IC2a (pin 3) via volume control potentiometer VR1 and a 22µF electrolytic capacitor. This capacitor ensures there is no DC flowing through VR1, which would otherwise cause a crackling noise when it is rotated.

IC2a buffers the voltage at the wiper of VR1 to provide a low impedance for inverting amplifier IC2b. IC2b has a fixed gain of 14.7, set by the 10kΩ and 680Ω resistors. The 100pF feedback capacitor improves circuit stability and reduces high-frequency noise.

Volume potentiometer VR1 is part of the feedback network from the output from IC2b to the input at the 220µF capacitor (from pin 1 of IC1a). Hence IC2a and IC2b form a feedback pair with the overall gain adjustable by VR1.

When VR1 is rotated fully anti-clockwise, IC2b's output is connected directly to VR1b's wiper. Thus IC2b is able to fully cancel the input signal (as there is zero impedance from its output to the wiper) and the result is silence (no output signal) from the preamplifier.

Conversely, when VR1 is fully clockwise, VR1b's wiper is connected directly to the input signal, which is then amplified by the maximum amount (14.7 times) by IC2b. At intermediate settings, the signal at the wiper is partially cancelled by the mixing of the non-inverted (input) and inverted (output) signals and the resulting gain is intermediate.

The way in which this cancellation progresses as VR1 is varied provides a quasi-log law gain curve.

IC1 needs input protection

Because the headphone amplifier may be turned off when input signals are present, IC1's input transistors can be subjected to relatively high voltages; up to 2.5V RMS or maybe 7V peak-to-peak. This will not damage IC1 immediately, but over many years, it could degrade the performance. This is because normally very little current flows through the op amp inputs and so the metal traces within the IC are thin. If enough current passes through the inputs (5mA or more), 'metal migration' can cause degradation and ultimately failure.

For that reason we have included small-signal Schottky diodes D15

Parts List: Hi-Fi Stereo Headphone Amplifier

1 PCB, available from the *EPE PCB Service,* code 01309111, 198 × 98mm
1 1U half rack case (optional)
1 12V AC 1A or 2A plugpack
1 10kΩ dual gang linear 16mm potentiometer (VR1)
2 500Ω sealed horizontal trimpots (VR2, VR3)
1 PCB-mount white switched RCA socket (CON1)
1 PCB-mount red switched RCA socket (CON2)
1 PCB-mount DC socket (CON3)
1 PCB-mount 6.35mm stereo jack socket (3PST) with extended pins (CON4)
1 PCB-mount right-angle SPDT mini toggle switch (S1)
2 M205 PCB-mount fuse clips (F1)
1 M205 1A fast-blow fuse (F1)*
6 PCB-mount 6021-type flag heatsinks (Element14 Order Code 1624531)
8 TO-220 insulating washers
6 TO-220 insulating bushes
2 plastic former bobbins
1 2m length 0.8mm diameter enamelled copper wire
1 25mm length 25mm diameter heatshrink tubing
6 PCB pins
4 M3 × 15mm machine screws
6 M3 × 10mm machine screws
10 M3 nuts
18 M3 flat washers
4 M3 nylon nuts with integral washers or M3 nylon nuts and washers
1 35 × 15mm section of tin-plated steel (eg, cut from a tin can lid)
1 3mm black plastic LED clip
1 knob to suit VR1
3 8-pin DIL sockets (optional)
2 small ferrite beads
1 250mm length 0.7mm diameter tinned copper wire

Semiconductors
3 LM833 dual low noise op amps (IC1-IC3)
1 7812 positive 12V linear regulator (REG1)
1 7912 negative 12V linear regulator (REG2)
2 TIP31 3A NPN transistors (Q11, Q23)
2 TIP32 3A PNP transistors (Q12, Q24)
2 BD139 1.5A NPN transistors (Q10, Q22)
2 BC328 PNP transistors (Q25, Q26)
2 BC338 NPN transistors (Q9, Q21)
6 BC549 NPN transistors (Q3-Q4, Q8, Q15-Q16, Q20)
10 BC559 PNP transistors (Q1-Q2, Q5-Q7, Q13-Q14, Q17-Q19)
1 3mm blue LED (LED1)
14 1N4004 1A diodes (D1-14)
4 BAT42 Schottky diodes (D15-D18) (or use BAT85)

Capacitors
2 2200µF 25V electrolytic*
11 220µF 25V electrolytic**
4 47µF 16V electrolytic**
2 22µF 16V electrolytic**
2 470nF MKT
2 150nF MKT
7 100nF MKT
3 10nF MKT
2 680pF C0G/NP0 ceramic
2 220pF C0G/NP0 ceramic
4 100pF C0G/NP0 ceramic

Resistors (0.25W, 1%)

4 100kΩ	2 680Ω
1 30kΩ	2 220Ω
3 22kΩ	6 100Ω
8 10kΩ	4 68Ω
10 2.2kΩ	2 47Ω
4 1.8kΩ	2 43Ω
2 1.1kΩ	4 22Ω
1 1kΩ	6 10Ω
2 910Ω	8 1.2Ω (1% or 5%)

Notes
* For driving speakers, upgrade the plugpack to 12V AC 2A, the fuse to 2A and the power supply capacitors to 4700µF 25V (diameter ≤16mm, height ≤30mm, eg, Futurlec C4700U25E105C).
** Low ESR 105° types can be used if their diameter is no more than 6.3mm for 22µF/47µF and 8mm for 220µF.

and D16 to protect pin 3 of IC1a (and D17 and D18 for pin 5 of IC1b) when the unit is switched off but a large signal is applied. They clamp the voltage at that input to within ±0.3V of the supply rails under normal conditions, preventing current flow through the op amp input transistors should their junctions be reverse-biased.

So, if the unit is off and the supply rails are zero, the input voltages will be similarly limited to ±0.3V.

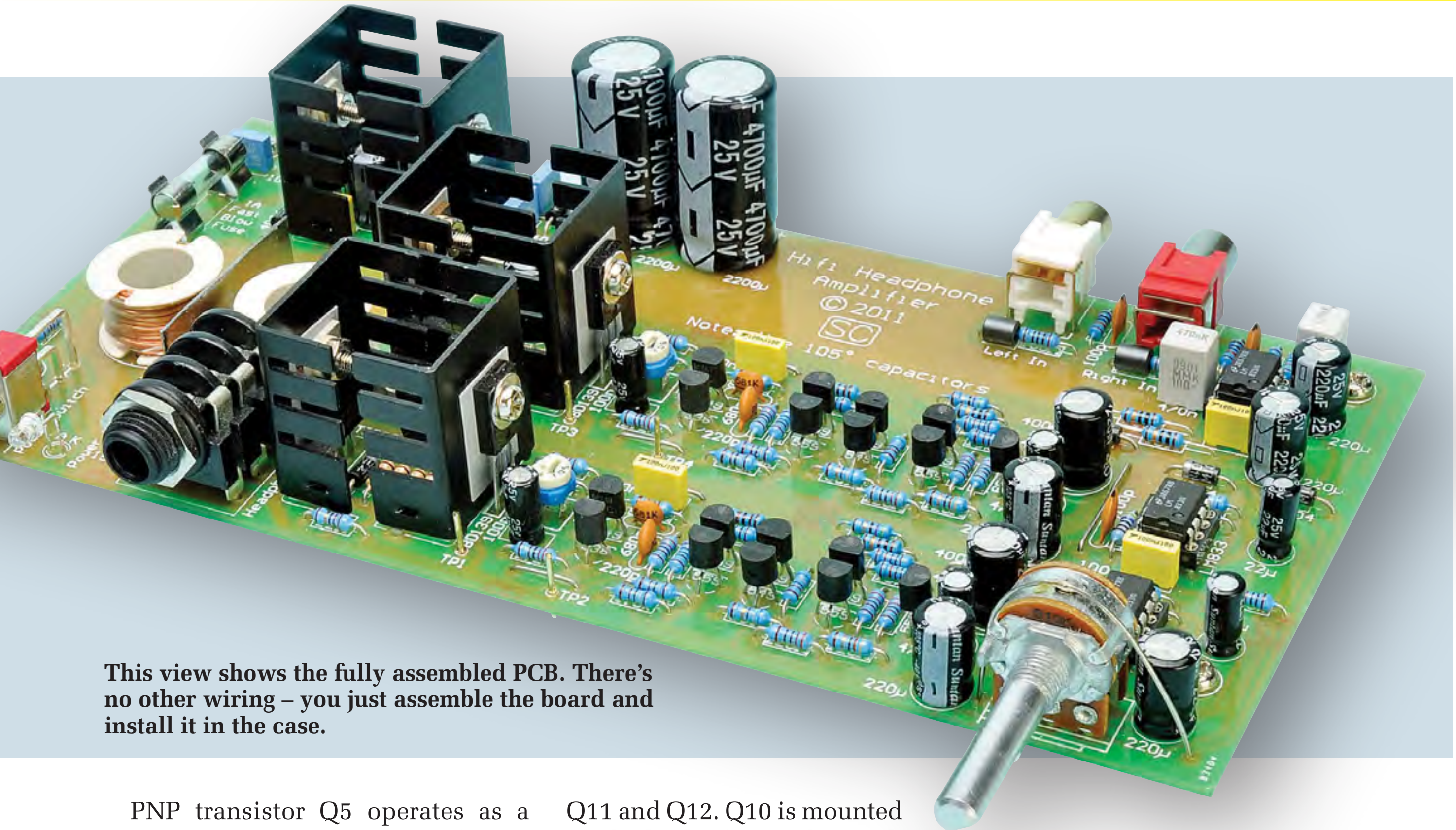
The BAT42 diodes have been carefully selected to clamp the op amp input voltages appropriately without having so much leakage current that they will introduce distortion into the signal (Schottky diodes normally have a much higher reverse leakage current than standard silicon diodes). For more information on protecting op amp inputs, see Analog Devices, tutorial MT-036, *Op Amp Output Phase-Reversal and Input Over-Voltage Protection*.

We also tested BAT85 diodes. These have slightly higher capacitance when reverse-biased (10pF compared to 7pF) and a significantly higher reverse leakage current (400nA at –15V/25°C compared to 75nA). However, testing shows no measurable increase in distortion with these in place of the BAT42s, so they are an acceptable substitute.

Amplifier circuit

Low-noise PNP transistors Q1 and Q2 are the differential input pair, with the base of Q1 being the non-inverting input to the amplifier and the base of Q2 being the inverting input. Q1's base is tied to ground by a 910Ω resistor (to match the 900Ω source impedance at the base of Q2) and is bypassed by a 100nF capacitor to reduce high-frequency noise.

The signal from the preamplifier is fed to the base of Q2 via a 1.8kΩ feedback resistor, so that the amplifier works in the inverting mode. 1.8kΩ is the lowest value resistance that IC2b can drive in parallel with its own feedback network.



This view shows the fully assembled PCB. There's no other wiring – you just assemble the board and install it in the case.

PNP transistor Q5 operates as a 3mA constant-current source (0.65V ÷ 220Ω) to feed the Q1/Q2 input pair. Negative feedback for current regulation is provided by another PNP transistor, ie, Q6. It has a bootstrapped collector current sink (two 10kΩ resistors and a 47µF capacitor), so that it operates consistently.

NPN transistors Q3 and Q4 form a current mirror for the input pair, with 68Ω emitter resistors to improve its accuracy. Any difference in the current through Q1 and Q2 must then flow to the base of NPN transistor Q8. So Q1-Q5 form the transconductance stage of the amplifier.

Together, Q8 and Q9 form a Darlington-like transistor, configured as a common-emitter amplifier. PNP transistor Q7 acts as a constant-current source for its collector load, sourcing about 15mA (0.65V ÷ 43Ω). Q6 provides current regulation feedback for Q7 as well as Q5.

The 680pF and 220pF capacitors between Q9's collector and Q8's base, together with the 2.2kΩ resistor from their junction to the negative rail, form the 2-pole frequency compensation scheme mentioned earlier. Together, transistors Q7-Q9 are the voltage amplification stage.

V_{BE} multiplier

Between Q7 and Q9 is Q10, which functions as a V_{BE} multiplier to set the quiescent current for output transistors Q11 and Q12. Q10 is mounted on the back of Q11's heatsink so that its junction temperature tracks the output stage. Thus, its V_{BE} tracks that of the output transistors (Q11 and Q12), so the bias voltage varies to compensate for changing output transistor temperature, keeping the standing current through them more or less constant.

VR2 is used to adjust this current, while the 2.2kΩ resistor prevents the bias from becoming excessive if VR2's wiper goes open circuit, as it may do while it is being trimmed. A 47µF capacitor filters the bias voltage, improving distortion performance when the output voltage swing is large.

The resulting bias voltage is applied between the bases of output transistors Q11 (NPN) and Q12 (PNP) via 22Ω stopper resistors, which prevent parasitic oscillation. Each output transistor has a 0.6Ω emitter resistor (two 1.2Ω resistors in parallel) which helps to linearise the output stage and stabilise the quiescent current.

Current limiting

While it's always a good idea to plug and unplug the headphones while the power switch is off, we can't rely on that and we don't want the output transistors to blow when it happens. Therefore, both Q11 and Q12 are protected against over-current conditions.

Q11 is current-limited because the 15mA current source (Q7) sets a maximum limit for its base current. According to the TIP31 data sheet, at 25-125°C, the maximum collector current will be about 1.25A; well within its safe operating area (SOA) as long as the short-circuit is brief.

Q12 is more of a concern because Q9 can sink significantly more than 15mA. The 10kΩ resistor at Q8's collector ultimately limits how much current Q9 can sink as follows. Q8's maximum collector current is around (12V – 0.7V) ÷ (10kΩ + 2.2kΩ) = 1mA. Q9's maximum current gain figure is around 165 (according to the BC338 data sheet), so the maximum Q9 can sink is about 165mA. Hence Q9 is a BC338 (a BC549 has a continuous collector current limit of 100mA).

However, if this much current were sunk from Q12's base then it would fully saturate (turn on hard), exceeding its SOA and possibly causing it to fail. Q25 and D7 prevents this. Should the current flow through Q12's collector-emitter junction exceed 2A (within its SOA), the drop across the 0.6Ω emitter resistor exceeds 2A x 0.6Ω = 1.2V.

At this point, Q25's base-emitter voltage increases beyond 1.2V – 0.6V = 0.6V and so Q25 starts to turn on, shunting current around Q12's base-emitter junction and preventing Q12 from turning on harder. Any current sunk by Q9 beyond that necessary for Q12 to pass 2A goes through D7 and Q25 rather than Q12's base-emitter junction.

Output RLC filter

The output filter isolates the amplifier from its load, improving stability. Because this amplifier circuit is already fairly stable (thanks to its simple output stage), we can get away with slightly less inductance than usual (4.7µH rather than 6.8µH or 10µH). We can thus use a thinner gauge wire, which is slightly easier to wind, for roughly the same DC resistance.

Ideally, the output filter should be optimised for the expected load impedance, but because headphones have such a wide range of impedances, all we can do is compromise and specify an intermediate value. As a result, for higher impedances, the amplifier has a slightly elevated response at above 20kHz (see Fig.5).

For 8Ω operation, there is a very slight roll-off at the high-frequency end of –0.02dB at 20kHz. At around 10-12Ω, the high frequency response will be virtually flat and then for higher load impedances, up to infinity, the gain is as much as +0.13dB at 20kHz. The increase is slightly lower (+0.09dB) for the most common impedances of 16Ω and 32Ω. This deviation is so small as to be imperceptible.

In fact, all our amplifier designs using this type of output RLC filter (devised by Neville Thiele) have such a response with higher than usual output impedances or no load.

Power supply

The 12V AC plugpack plugs into an on-board DC connector (CON3). A 1A fuse protects the plugpack in case of a board fault or overload.

The power switch (S1) is in the ground leg so that the tracks to and from it (near the edge of the PCB) have minimal AC voltage. This eliminates electrostatic radiation, preventing any coupling to nearby signal tracks.

The incoming AC is half-wave rectified by diodes D1 and D2, with three 10nF metal film capacitors for RF and switching suppression. The resulting ±16V rails (nominal; under light load, closer to ±20V) are regulated to ±12V using 3-terminal regulators REG1 and REG2.

So why are we regulating the supply for the whole device rather than just the op amps? Essentially, it is because the amplifiers draw so little power when driving headphones that they might as well run off the regulated rails. In addition, the unregulated supply ripple is 50Hz because of the half-wave rectifiers (rather than 100Hz). The regulated supply rails give a lower hum and noise figure.

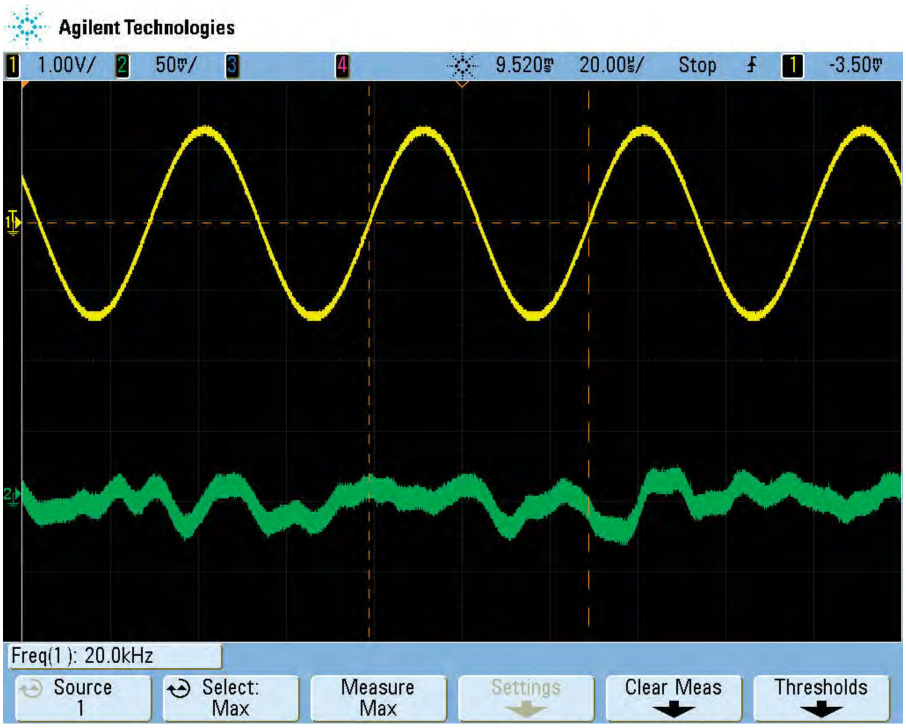


Fig.8: the green trace in this scope grab shows the distortion residual for 100mW into 32Ω at 20kHz. Most of this is actually noise with very little harmonic content. Into lower load impedances (eg, 8Ω) the distortion becomes more apparent and is primarily third harmonic, with some higher harmonics.

Switch-on/off behaviour

The circuit has been carefully designed to avoid loud thumps from the headphones when the unit is switched on or off. With a power amplifier, this is usually taken care of with an output muting relay that is also used for speaker protection. Since this amplifier has a low power output and a limited output current, a protection relay isn't necessary.

That is not say that you won't hear any thumps at all. That will depend, in part, on the efficiency of your headphones. However, any thumps you do hear will be very slight.

This has partly been achieved by removing the capacitor which would typically be between Q5's base and the positive rail. This is not necessary with a regulated supply and if present, it delays the operation of the constant-current source controlled by Q5 by several hundred milliseconds at switch-on. This would have caused a loud thump from the headphones had it been retained.

Diodes D11 and D12 (D13 and D14 in the right channel) are also important for proper switch-on behaviour. While the ±12V regulated rails are already protected to prevent the positive rail from going negative and vice versa, the RC filtered supply rails for the early amplifier stages can still suffer from this problem unless extra steps are taken. That's because the filter resistors isolate the capacitors from the clamp diodes D4 and D6.

Without D11 and D12, the positive filtered rail could be briefly pulled negative and this would cause an amplifier output excursion.

The different positive and negative rail filter resistors (10Ω and 47Ω respectively) allow the positive rail to come up more quickly, which also helps achieve a clean switch-on. Together, these details allow the amplifiers to operate normally just milliseconds after both filter capacitors are partially charged.

Similarly, diodes D9 and D10 clamp the RC-filtered supply for the op amps in the preamplifier. Without these, the op amp input transistors

A half-size 1-unit steel case is used to house the assembled *Headphone Amplifier* PCB. Part 2 next month has all the construction and setting-up details.

may become briefly reverse-biased at switch on, causing supply current to flow into the AC-coupling capacitors and again causing a thump to be generated.

Finally, the 1kΩ resistor in parallel with D10 discharges the op amp negative supply rail faster than the positive rail when power is removed. The op amps are prone to oscillation when their supply capacitor is mostly discharged and this can cause a 'chirp' at switch-off. With the 1kΩ discharge resistor, this chirp is made very short and often eliminated entirely.

Increasing the output power

While the circuit as presented is capable of driving loudspeakers, a few small changes can usefully increase the power output. If the 2200µF filter capacitors are changed to 4700µF, it increases the current they can supply before regulator drop-out begins.

Also, a 12V AC 2A plugpack can be used in combination with a higher rated 2A fuse. This increases the available output power a little more. The THD+N vs power graph (Fig.7) shows the performance when both modifications are incorporated.

Next month

Next month, we will present the construction details and describe the setting-up procedure.

*You won't believe how good they sound . . .
and your friends won't believe you built them!*

"Tiny Tim" Horn-Loaded Speaker System

This low-cost speaker system uses a single 4-inch driver to give surprisingly good bass and treble response. It is quite efficient and only needs a low power amplifier to give excellent sound levels.

By Allan Linton-Smith and Ross Tester

This speaker system turns heads, not only because it looks quite different from the speaker systems you may be used to, but more importantly because it sounds so impressive.

It does not use bulky and expensive eight, ten or twelve-inch drivers and there are no tweeters or crossovers.

Instead, the single driver in each box is a four-inch model, which costs as little as £15.00. Add some pieces cut from a sheet of plywood, which costs perhaps £40, some glue and a few hours of construction time and you'll have a speaker system which easily competes with much-higher-priced commercial units on the market today. And yes, we know that there are quite a number of tower and mini-tower speakers on the market right now, many with multiple drivers and all sorts of claims. Quite simply, we believe these are better than anything we've heard recently at anything like the price!

The secret to such a high-performing speaker is in the design of the cabinet. Unlike the simple bass-reflex or other

ported designs you're used to, these are actually rear-loaded horns. They look difficult to build, but providing you're accurate with your woodwork (or you use someone who is!) they are surprisingly simple to put together.

The drivers

You have a choice of 4-inch drivers for this design. The cabinets are perfectly matched to – and in fact were originally specifically designed for the high-performing Fostex FE103EN models.

But we tried a couple of other drivers: the Altronics C0626 and Jaycar CS-2310 models, which are significantly cheaper than the Fostex. And while they might not perform *quite* to the level of the Fostex drivers, most people would be very happy with the cheaper approach.

Having said that, several of our colleagues commented that they thought enclosures fitted with the Altronics drivers actually sounded the best!

While the Fostex is a single-cone driver, the Altronics C0626 is a twin-cone model and the Jaycar is a coaxial unit with separate miniature tweeter fed by a bipolar electrolytic capacitor.

The first two speakers have the advantage of simplicity and there is no problem with phase shift in a crossover network, albeit even the simple crossover capacitor of the Jaycar unit.

All three drivers have the advantage of using a single driver with its phase coherency over a wide range of frequencies. This helps in the realistic reproduction of voice, instruments or complex orchestration and in accurate sound staging or positioning of each instrument.

Just a note about the Jaycar CS-2310; it's intended as a car speaker and its nominal impedance is 4Ω, so you will need to make sure your amplifier can handle this low impedance (fortunately, these days, most can). The Fostex and Altronics drivers are both 8Ω.

So which to choose?

If you're looking for 'most bang for your buck' the Altronics would be a good choice because they are the most efficient (95dB/W @ 1m) vs 89dB for the Fostex and 83dB for the Jaycar unit. Offsetting that lower efficiency is the fact that the Jaycar driver will actually receive twice as much power as the other two (because it has half the impedance) for a given volume setting from the amplifier. This will mean that the difference in efficiency will be less apparent than the raw figures might indicate.

The Altronics and Jaycars are similarly priced, at about £25 a pair for the Altronics *vs* £15 for the Jaycars, but you'll pay much more for the Fostex drivers. You can compare the three drivers in the spec table below.

The cabinet design

The enclosure design for this speaker (which you can download at **www.fostexinternational.com/docs/speaker_components/pdf/FE103En.pdf**) can be regarded as a cross between a bass reflex vented enclosure and a horn-loaded enclosure. Horn loading can be thought of as an efficient means of coupling between the relatively heavy mass of the speaker to the much lighter mass of air.

Horns have been used for a very long time. For example, they have been used for centuries in musical instruments and as megaphones – the very first horn speaker. And of course, early wireless sets and gramophones used a horn-loaded speaker. In all of these early examples, efficiency was paramount.

The tower speaker we are using here uses the 4-inch driver as a direct radiator for the upper frequencies and a horn radiator for the lower frequencies. The internal construction of the tower is actually a folded horn with each section being longer and larger in cross-section, to approximate the exponential taper of an ideal horn.

While efficiency is a big advantage of a horn speaker system, they do not necessarily result in the smoothest bass response. However, in our case where we are using tiny drivers, we get a much more extended bass response than could normally be expected with their relatively high free-air cone resonances.

Anyone who is reasonably competent in woodworking and has a selection of suitable tools should be capable of putting these cabinets together.

In fact, we think these speakers would make an excellent 'project of choice' for many students doing craft,

Manufacturer's specifications	**Fostex** FE103En	**Altronics** C0626	**Jaycar** CS-2310
Price per pair (£ approx)	100	25	15
Voice coil dia (mm)	20	-	-
Impedance (ohms)	8	8	4
SPL (dB/W@1m)	89	95	83
Rated input (W)	5 to 15	8 to 15	15
Magnet	ferrite	ferrite	ferrite
Magnet wt (grams)	193	-	-
Net wt (grams)	580	-	-
Baffle hole dia (mm)	93	93	93
Cone area (sq m)	0.005	-	-
R_e (ohms)	7.5	-	-
Free air resonance (Hz)	83	120	122
VC inductance (mH)	0.0398	-	-
Q_{ms}	2.747	-	4.28
Q_{es}	0.377	-	1.88
Q_{ts}	0.33	-	1.31
M_{ms}	2.55g	-	-
V_{as} (Litres)	5.95	-	3.31
X_{max} mm	0.6	-	-
Frequency response	83-22kHz	120-20kHz	90-18kHz
Measured response			
Frequency response ±5dB	60-15kHz	70-15kHz	-
Distortion (THD+N) [1kHz 90dB]	0.45%	0.65%	-
Sound pressure level 1kHz 1watt/1m (dB)	92.65	89.97	-

The enclosures are designed for the Fostex FE103En drivers, but we've found the much-cheaper Altronics C0626 or Jaycar CS-2310 do an admirable job as well: in fact, some of our staff members commented they sound better!

technology or design courses: do the cutting, assembly and finishing in the woodwork room, mount the speakers and wire them in the technology or electronics classes – and best of all, they won't break the bank. And after they earn top marks, they'd have speakers mum and dad would be proud to put in the lounge!

Plywood is a must!

The pieces for both boxes can be cut from one and a half sheets of 15mm plywood (1220 × 2440mm and 1220 × 1220mm). In fact, with care you'll get all bar one small piece (no.7) from one sheet. See Fig.1, it shows how the pieces are cut – the first cut needs to be made where shown.

The missing piece, (235 × 150mm), could even be cut from scrap because it is internal and won't be seen.

Note that this cutting diagram does assume an 'imperial' size sheet; some suppliers have taken to making their sheets 2400 × 1200 – this size is not quite large enough as it cannot make allowance for the saw cuts. Your supplier should be able to advise you of the exact size of their sheets. If they are 2400 × 1200, then you'll definitely need a second (half) sheet.

We used good quality Aspen Birch veneer because of its fine grain and appearance, but you can choose the finish to match your decor. You *could* use plain plywood, sand it smooth and paint or stain it to your tastes.

Note that we **DO NOT** recommend the more commonly available MDF because it is 16mm thick – the extra 1mm will decrease the width of the 'horn' by a cumulative 6mm and will *drastically* affect performance.

You will note from the photos and diagrams that the horns are built up by layers of plywood pieces. It is absolutely vital that these pieces are very accurately cut to size. If you don't have either the equipment or the skills to cut to close tolerances (to the millimetre!) we suggest you approach a local kitchen cabinet maker – most will do it for a reasonable cost; indeed, many will be

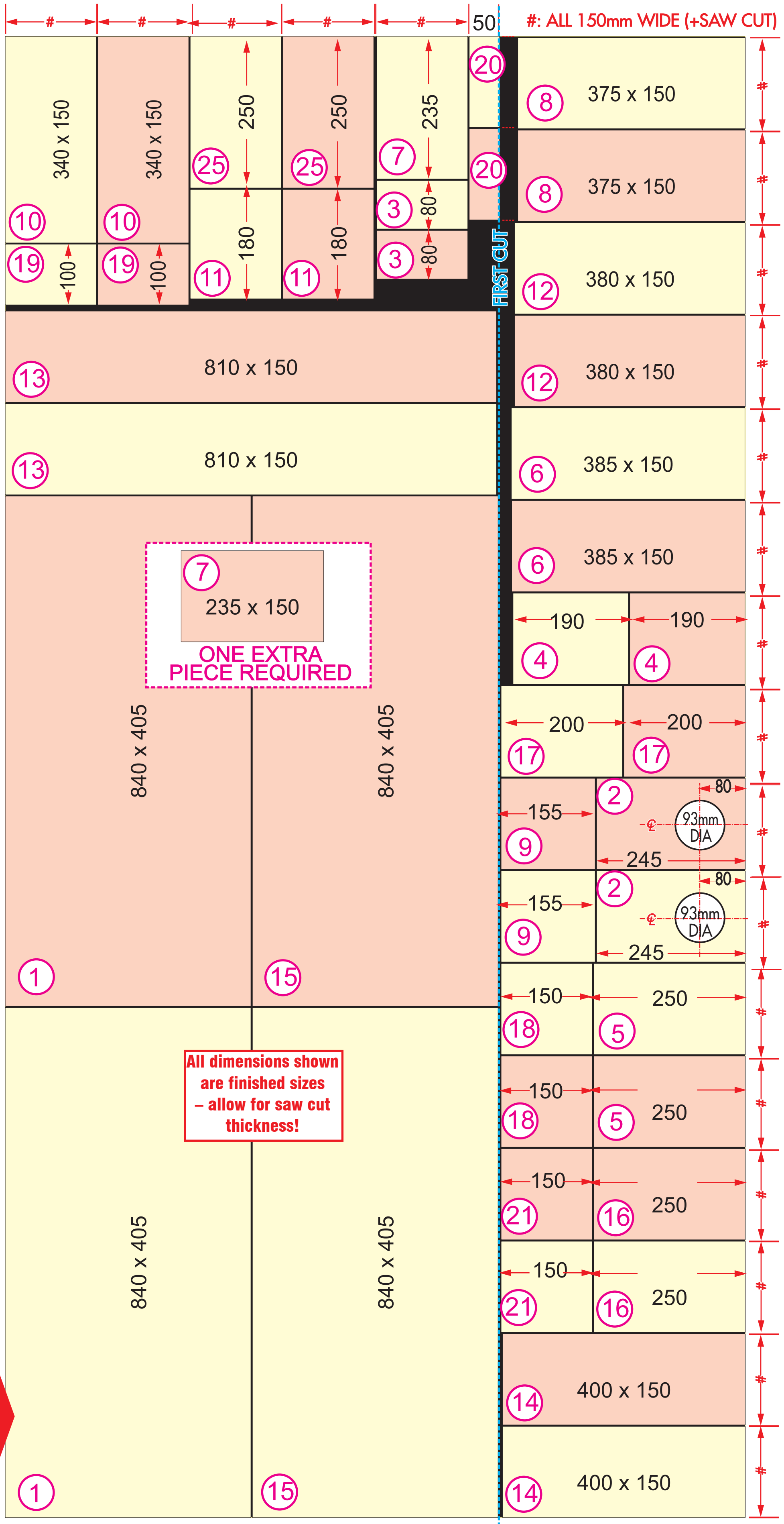


Fig.1: it's a tight fit, but all except one piece (one of the '7s') can be cut from a sheet of 1220 × 2440 × 15mm ply. This assumes a saw cut thickness of 2.5mm, about normal for a kitchen cupboard maker. Note where the first and second cuts are made. The lemon coloured pieces are for box 1, pink for box 2.

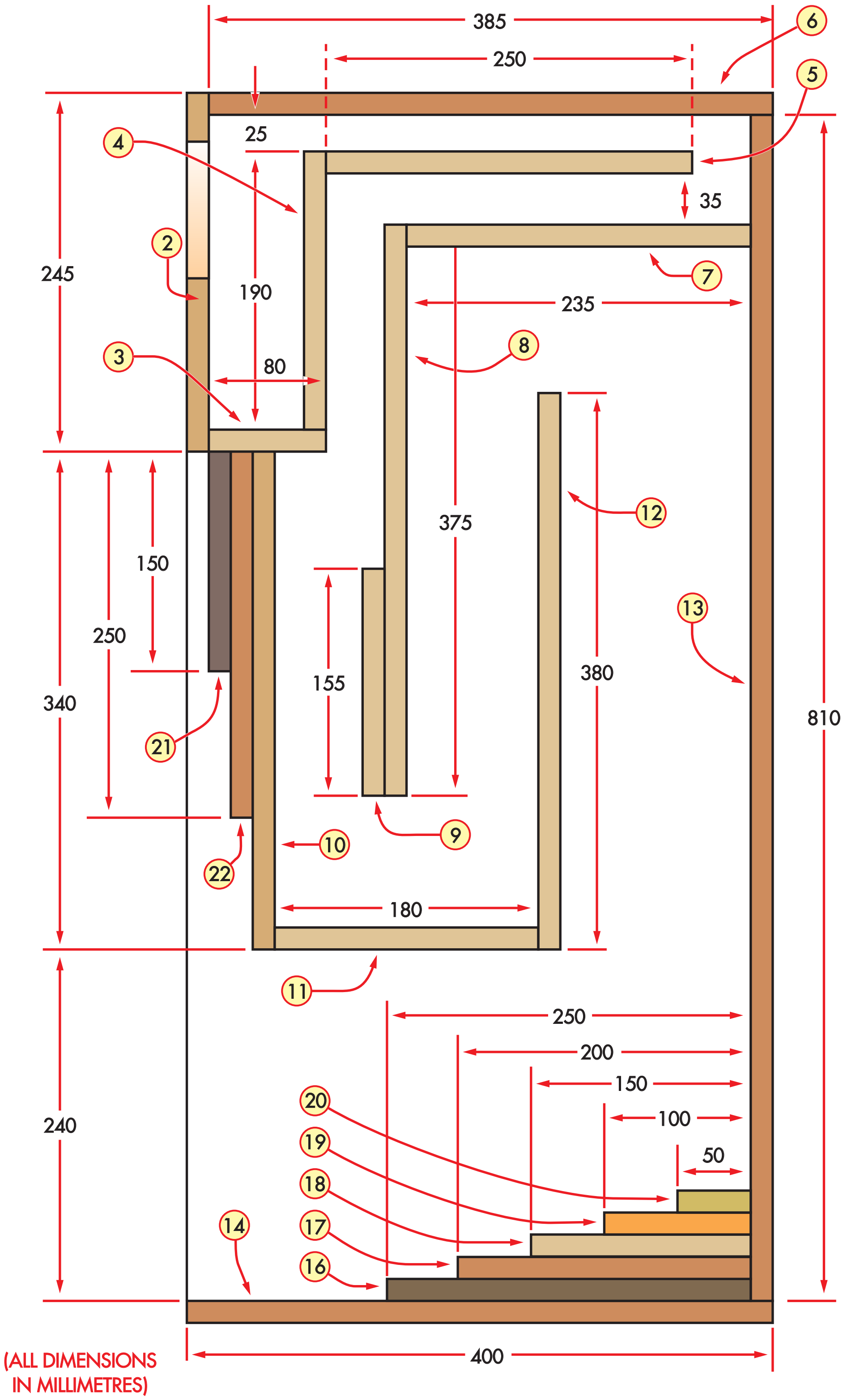


Fig.2: looking down on the right side, without the side panels, here's how all the pieces glue together to form the loaded horn. The photographs later in this article will help explain how it all goes together.

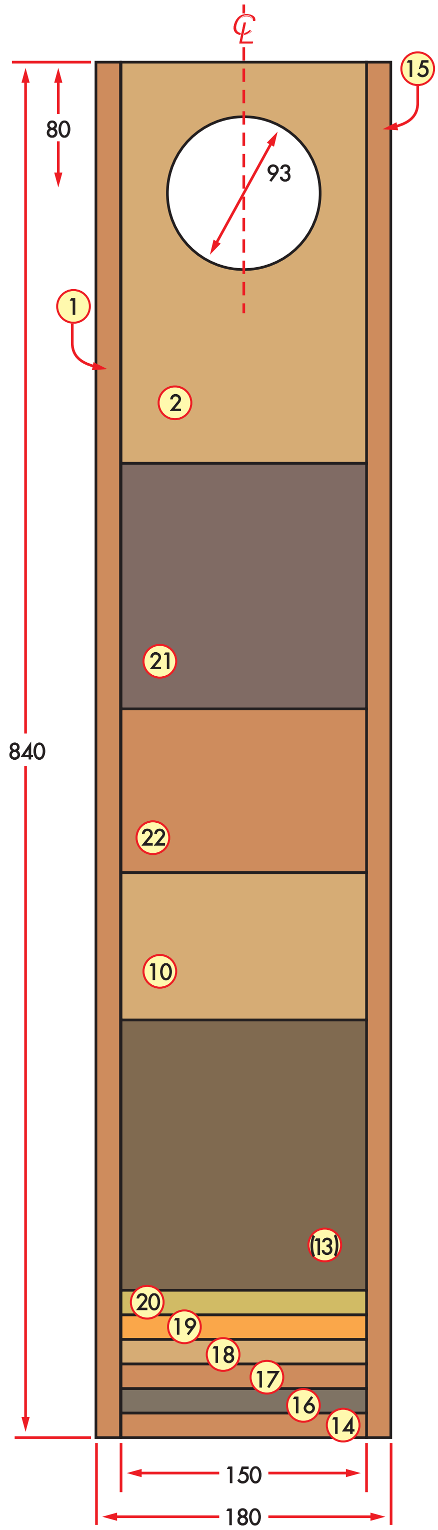


Fig.3: and here's the front-on view with the side panels fitted. Piece 13 is actually the rear panel.

able to supply the veneered plywood as well. Just don't let them talk you into MDF (a lot of kitchen cabinets are made from that stuff these days!).

Incidentally, we investigated a major hardware chain offering a cutting service and found them unacceptable for two reasons: first, they guaranteed a tolerance of no better than 5mm – useless as far as this project was concerned and second, they only had 'construction grade' 15mm ply.

Now that would be OK if you only wanted a painted surface, but even then, a fair amount of sanding and finishing would be required. Also, they only had full 'metric' sheets (2400 × 1200mm) in stock and, as expected, they tried to talk us into MDF, which did come in half sheets! It may be that in time, some of the kit suppliers will

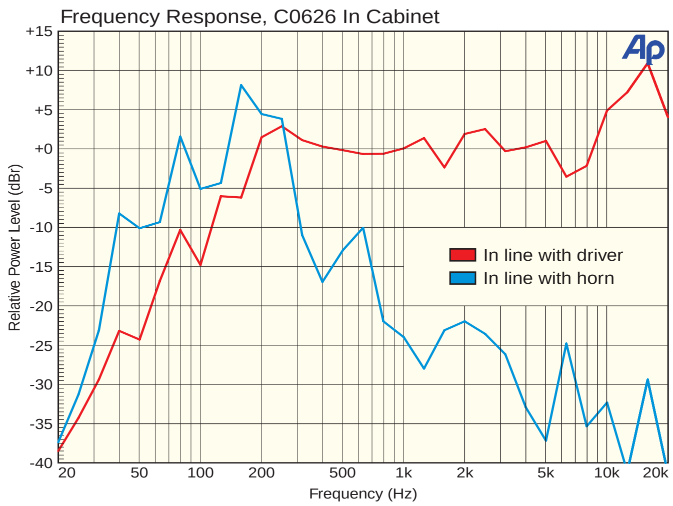


Fig.4: frequency response plots of the Altronics drivers in the horn-loaded cabinet. The red trace is the on-axis flat response and the blue trace shows the output from the mouth of the horn section.

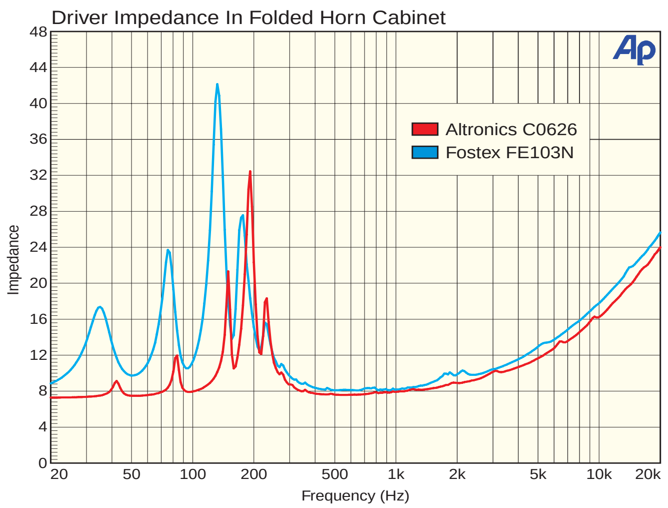


Fig.5: impedance curves of the Altronics and Fostex drivers, with multiple peaks resulting from the horn loading. This is partly a result of the much higher loading to the rear of the driver's cone.

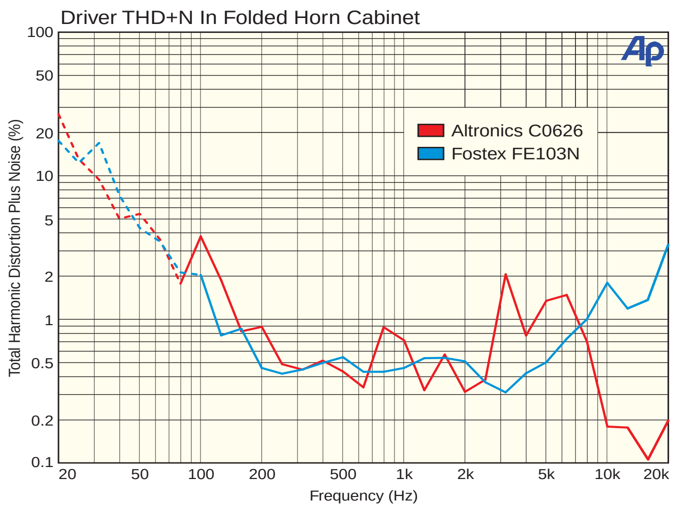


Fig.6: harmonic distortion of the Altronics and Fostex drivers. Note that the distortion of both drivers is quite low over much of the audible range but rises at the low end, partly as result of the horn loading.

produce a full kit of parts – keep an eye on their advertisements.

The amplifier

Another feature of these speakers is their ability to handle a range of amplifiers. While they're ideally suited to lower-power amplifiers (again, that school project market springs to mind), they can handle more, with sound output to match. All three speaker drivers mentioned above are rated at 15W maximum input, so you certainly *cannot* run them flat out from a high power amplifier.

We've run them from amplifiers as low as 5W output (eg, *The Champion* from January 2014) and we've run them (judiciously!) from the much higher power amplifiers.

However, even running from *The Champion* they certainly filled our large warehouse with sound!

Performance

We tried these with all three speaker drivers mentioned above. As you might expect, the Fostex drivers gave the best bass response – but you do pay for it! The others were surprisingly beefy!

Fig.4 shows two frequency response plots of the Altronics drivers in the horn-loaded cabinet. The red trace was taken with the microphone on axis and very close to the tweeter cone of the driver, and it shows a reasonably flat response to 10kHz and rising to a peak at around 18kHz. The blue trace was taken with a microphone adjacent to the horn section and it measures the augmenting effect of the horn loading.

As you can see, the response is quite well maintained to below 60Hz (quite similar to the much more expensive Fostex drivers). Generally speaking, at distances of over 2m, the response will be a combination of the two curves.

Fig.5 shows the impedance curves of the Altronics and Fostex drivers. These are quite different to the equivalent curves you would see with the drivers in a bass reflex enclosure, which normally shows two impedance peaks in the low frequency region. The horn loading results in multiple peaks and this is partly a result of the much higher loading to the rear of the driver's cone. It also results in better bass, as shown by Fig.4.

Fig.6 shows the harmonic distortion of the Altronics and Fostex drivers and again the cheaper Altronics driver gives a good account of itself. Note that the distortion is quite low over much of the audible range, but rises at the low end, partly as a result of the horn loading and also the fact that the fundamental output drops markedly at very low frequencies.

Building the speakers

We have simplified each step so you shouldn't have any problems. Build one speaker box at a time – otherwise mistakes are much more likely. Do not rush things and make sure you understand each step before diving in!

Again, we must emphasise the need for very good accuracy in cutting out the panels. Using a hand-held saw of any description will usually result in errors and out-of-square cuts which will inevitably lead to air leaks or malfitting panels. The panels are butt-glued, so 'squareness is next to godliness!' To that end, wipe up any glue excess as you go.

And to ensure perfect alignment, the enclosures need to be assembled on a completely flat surface – a work bench is fine if it is flat and stable; otherwise, use a (say) concrete floor with some single newspaper sheets spread on it.

Assembling the cabinets

Step i We are assuming you already have all your pieces accurately cut out. Number each piece as shown on the diagram – use 'Post-It Notes' or similar to avoid leaving glue – in any case, stick them to the 'bad' side of the plywood (ie, not the face side).

Step ii Using the diagram (Fig.2) as a guide, on one of the side panels (piece 1) use a pencil on the 'bad' side to mark out where all the pieces are going to go.

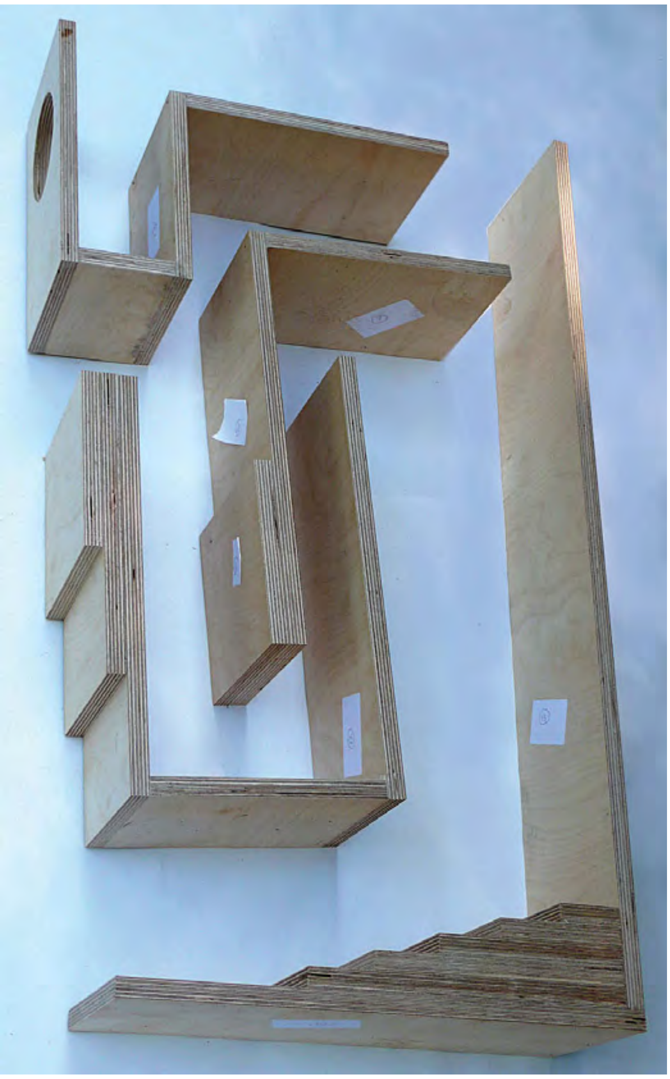
Step iii Take pieces 2 and 3 and first check their dimensions to make sure you have the right ones – we're about to glue them together and once stuck, you won't be able to get them apart. Use two or three small nails or panel pins to tack them together, then prise them apart without bending the nails and run a 3mm bead of glue* along the join. Push the nails back into the holes and gently tap them with a hammer until you are happy with the fit. Wipe off any excess glue with a damp rag.

If for some reason they haven't ended up where they should, light tapping with the hammer should get them right. You have about 10 minutes to move things around before the glue sets.

Clamps or a vice should be used to hold the pieces together to give a really good bond – the glued pieces should be ready to remove after about half an hour.

Take the completed pieces and place them on the side panel where they will go – but don't glue them in place just yet.

* We used a caulking gun and 'Parfix Maxi Nails Fast' water-based construction adhesive, which will bond wood to just about anything. It's cheap, it sets quickly (about 20 minutes) but gives up to 10 minutes or so of 'fiddle time' before the glue gets too tacky. This glue (or several other bonding adhesives) are available from most hardware outlets. NOTE: PVA wood glue is not recommended.



Lay out all the pieces on a flat surface so you understand how they all go together. Note the identifying 'Post-It' Notes.

Now we've glued all the pieces together and when dry, have then glued them in position on the left-side panel.

Step iv Repeat step iii for pieces 4 and 5.

Step v Glue pieces 2 and 3, and 4 and 5, together

Step vi Glue pieces 21, 22 and 10 together, using a square to ensure that the end is perfectly flat. Allow them to set for an hour or so, then glue them to the pieces you made in step v. (They glue to piece 3).

Step vii Now glue pieces 11 and 12 together, allow to set for an hour, then glue those to the pieces in step vi (they glue to piece 10).

Step viii Glue pieces 7, 8 and 9 together and set aside to dry.

Step ix Fit the input (banana) binding posts to piece 13 – drill two 3.5mm holes 50mm down from the top and 25mm apart.

Step x Now glue pieces 16, 17, 18, 19 and 20 together.

Step xi Glue pieces 6 and 13 together, using the side panel to keep them square while they set.

Step xii Glue pieces 13 and 14 together, again using the side panel to keep them square while they set.

Step xiii Now glue all the pieces together from step x, to pieces 13 and 14.

Step xiv Once all of the glue has set, you now should have everything ready to be glued to the side panel. Place all pieces accurately in position on the side panel.

Use small panel pins and clamps to hold your speakers together while the glue is setting. Any blemishes can be smoothed over later.

Here's the completed speaker box once the glue has dried. All that remains is a bit of tidying up, finishing the veneer with your desired stain or paint and then fitting the 4-inch speaker.

And here it is with a clear polyurethane finish. This shot of the rear of the speaker (from the top) also shows the input terminals in place. You can see how the rear panel and top are inset 5mm from the rear edge of the side panels.

Step xv Glue all those pieces in place. By now you should have a pretty good idea how much glue is used so you shouldn't have too much excess. If you do, don't waste time wiping it away – remember, you only have about 10-20 minutes before the glue sets so you need to work fairly fast.

Step xvi When everything is in place, take the other side panel (piece 15) and without applying any glue, place it on top of the whole assembly with some weights on top. If you have worked fast enough, the glue should still be wet enough so that you can move any pieces that need to be adjusted so they are flush with the side panel. It's most important that the front of the cabinet is flush to the side because that's the part that you see. Adjust it first, then the back if you have time (you won't see the back!).

Step xvii When the glue has dried, solder a 300mm length of figure-8 cable to the input terminals. Remember which is to the red and which is to the black (normally, stripe goes to '–' or black). Hang the other end of this wire out the front speaker hole.

Step xviii It's time to complete the enclosure. Add a bead of glue to all the edges and place the side panel in place, adjusting it again so that the front is aligned to the sides. Put the weights back on and wait until it dries.

Hopefully, you will have done it all correctly. . . now you get to do it all again with the second enclosure!

Finishing off

You can now carefully sand off any rough edges or dabs of glue, then stain, coat or paint your enclosures as you prefer. We simply applied a coat of clear polyurethane to the timber because the Aspen Birch veneer really shines with this treatment.

But remember, paint hides a multitude of sins if you have made any 'oopses' along the way.

When the cabinets are completely dry, cut two 150mm × 245mm pieces of cellulose wool (often sold under the brand-name 'Innerbond') and place them loosely behind the speaker area – but do not block the entry to the horn. We found that any packing in the horn reduced the bass by half (6dB) but the little packing behind the speaker had no effect on the bass. However, it did reduce the 'hollow' sound at mid frequencies, caused by standing waves and reflections.

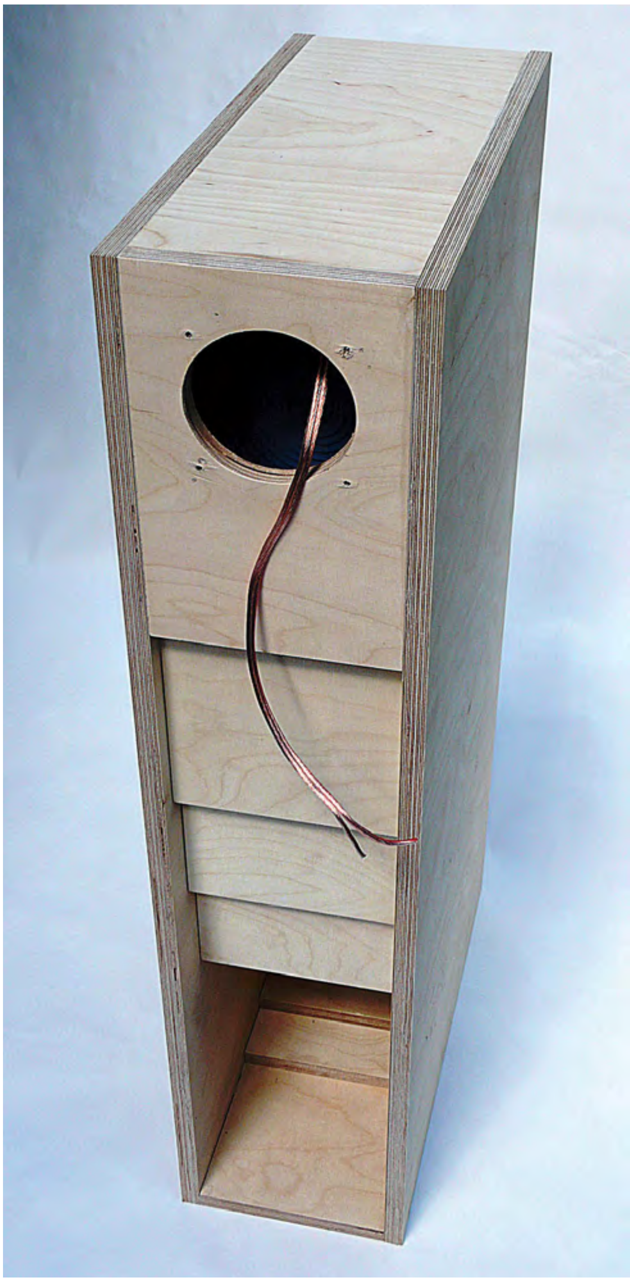
Fit the speaker drivers to the boxes, making sure you get the phasing (ie + and – connections) the same on both boxes. As a final check, briefly connect a 1.5V battery to the input terminals (+ to red, – to black) and watch the cone. Both speakers should move the same direction when connected the same way.

The drivers should have some form of gasket between them and the woodwork to ensure a seal. We wouldn't use silicone sealant – it works really well, but makes the speaker incredibly difficult to remove intact if you have to remove it for any reason. A large 'O' ring is ideal; at a pinch you could even use a large elastic band. Just make sure it seals all the way around as you tighten the four screws.

If you use the Jaycar drivers, fit the grilles over the front of each speaker. Of course, you can buy grilles to fit the Altronics or Fostex speakers. Grilles are almost mandatory if you have young people with prying fingers around: that speaker height is just about perfect.

Training the speakers

What's this? 'Training speakers'? Believe it or not, all speaker drivers 'straight out of the box' are a little stiff and benefit from being 'run in'. We allowed about two hours of continual music at reasonable volume before we were satisfied that ours were nice and mellow. You will certainly note a significant improvement over time, particularly in the bass response.



MAKE YOUR OWN PCBs

Part 2

Mike Hibbett takes a look at how to produce your own printed circuit boards (PCBs). In part 2 we look at installing the software and designing the board.

SOMETIMES, you need to look back to appreciate what you have. Looking over an old article in the January 2004 issue of *Everyday Practical Electronics* recently, I was drawn to the rather dated PCB designs employed (looking at my own project in particular!) and marvelled at how far we have come in the years between then and now. This wasn't a look back to the days of valves and cats whiskers – we are talking just ten years – but a lot has happened in that time. Manufacturing has transferred to mainland China, and the Internet connects hobbyists to professional electronics manufacturers around the world. It makes you wonder what will happen in the next ten years.

Installation

Let's kick off this month by installing EagleCAD, then take a look around the user interface. The installation program **eagle-win-7.0.0.exe** can be downloaded from the CADSoft website at **www.cadsoftusa.com/download-eagle**. At the time of writing this article, the program is at version 7.0

Before we start the installation, you should note that EagleCAD is a licensed product and it will prompt you during installation for a license file or network key. This is required if you have purchased EagleCAD. We will be using it in its *freeware* mode and will not be required to obtain any form of license key. (The program can also be run in a *freemium* mode, which has a few more options, but reverts back to freeware after sixty days use. That's not terribly useful for hobbyists, so we will ignore it.)

Once the file has downloaded, double-click on it to launch the installation process. You can click through the options presented, accepting the defaults until the 'Eagle License' dialog appears. At this point, select 'Run as Freeware'. The installation will complete and the application will launch automatically. You may now delete the installation program.

If you have used earlier versions of EagleCAD you are going to be in for a bit of a surprise – CADSoft have refreshed the icon style, giving it a Microsoft Windows 8 'Metro' style look-and-feel, as you can see in Fig.1. However, the changes are largely skin deep. For this series of articles we are going to assume that you are a novice, so the user interface changes will not be an issue. Version 7 is also backwards compatible with designs made in earlier versions of the program, so it is well worth performing the upgrade if you have not already done so.

What do we get?

Having installed the program and been presented with the Tools control panel, let's have a very quick summary of what we are able to do with our 'free' install:

- Create a single-paged schematic
- Create double-sided boards up to 100mm × 80mm is size;
- Produce standard PCB manufacturing data

Turning the question around, what are we *not* able to do with the free version:

- Create multiple pages of schematics (for a single design)
- Create boards larger than 100mm × 80mm
- Create boards with more that two copper layers
- Use the designs for commercial purposes

That first point is no issue for hobbyist designs – we have never found the 'single-page circuit diagram' to be an issue. The board size limitation is rarely an issue, and when it has been we have simply split the design into two or more boards. Likewise, being able to create only single or double-sided PCB designs is no issue at all for hobbyists; in 30 years of making our own boards we have yet to design a four (or greater) layer PCB, since the cost of a four-layer board is significantly greater than a two-layer board. Having said that, the costs are dropping, so perhaps the time is approaching for hobbyist-created four-layer boards!

However, the last point is important to note: you are only permitted to use the program for your own personal

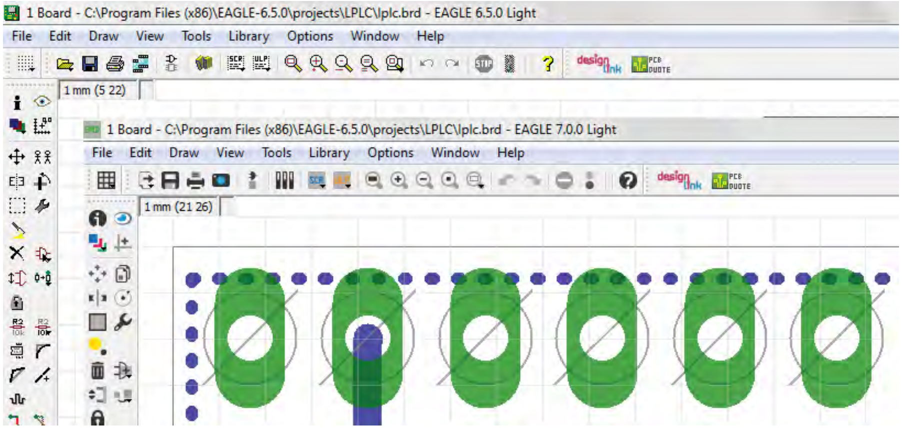


Fig.1. New user interface

use. That's not unreasonable given that the price of the commercial version of the above setup is just 62 euros (around £50).

Control panel

On starting the application, you are first presented with the control panel, as shown in Fig.2. This dialog displays a summary image of the currently selected design on the right, and on the left a hierarchical tree view of the high level functions available with the program:

Libraries
Design Rules
User Language Programs
Scripts
CAM Jobs
Projects

This gives us the opportunity to start working through the 'language' of CAD programs. Let's explain each of those options in turn.

Libraries

Individual component types, such as a 1/4W resistor or 0.2-inch pitch disk ceramic capacitor are represented within the program by a 'device'. Each device consists of two parts: a 'symbol', which is shown on the schematic, and a 'package', which is shown on the PCB drawing. Although they represent the same thing, it is desirable to have two views of the part for the two different 'views' of your design – the *schematic* displays the logical connections between components, while the *board* displays the physical connections between those parts. It's important to note that a device exists in the library only for each unique physical component type; the actual *value* of a component is entered when you are creating a design, and is one of the 'attributes' of each component placed in your schematic. All the same, there are hundreds if not thousands of devices in the library (and more are available to download for free across the Internet) so they are organised in a directory-like structure, and the tool provides an excellent – and necessary – search facility.

Design Rules

An excellent feature offered by all modern CAD programs is the ability to analyse your board design for errors. This can be done at two points: in schematic entry, where an 'electrical rules check' can be performed, and during board design, where a 'design rules check' can be performed. The electrical rules check ensures that all mandatory I/O and power pins have been connected to, and that two or more output pins have not been shorted together. (Every pin on a component has a 'type' attribute that can be 'INPUT', 'OUTPUT' and 'POWER', for example.) Design rules check is complex, and is used to confirm that your physical layout of the board does not exceed the capabilities of the PCB manufacturer – such as how thin tracks may be, how close to each other or the edge of the board tracks may run, minimum drill diameter and so on.

Each manufacturer has their own specific capabilities and limitations; some of them operate two or more design standards, with the more challenging standard costing more. Fortunately, all of these capabilities and limitations can be expressed in a design rules file. Checking the design automatically is absolutely essential; it takes just a few seconds, and will find issues that you would struggle to find unaided. Failing to check your board will *at best* result in the manufacturer rejecting it; *at worst*, they make it and you find your board does not work. Moral of the story: check your board, and check it often!

User Language Programs (ULPs)

It is possible to write programs in the 'C' programming language that can be run by Eagle. These programs can make use of internal functions of EagleCAD to perform complex operations. ULPs are an advanced topic and we will not cover them in this initial article series.

Scripts

Similar to (but much simpler than) ULPs, scripts are simply a list of normal user commands collected in a file. These can be useful if there is a series of commands that you use frequently. Eagle ships with a dozen or so scripts. The important one is **eagle.scr**, which is run when eagle starts up. You can modify this to configure Eagle as you see fit, if you wish.

CAM Jobs

The term 'CAM Jobs' refer to a series of dialogs that can be run to convert the board design into industry standard formats that can be understood by PCB Manufacturers' drilling and board etching machines. Although there are dozens of PCB programs, there are (thankfully) only one or two PCB manufacturing standards. Each 'Job' references a particular manufacturing data format. We will explore these later in the article series when we create PCB data for manufacture.

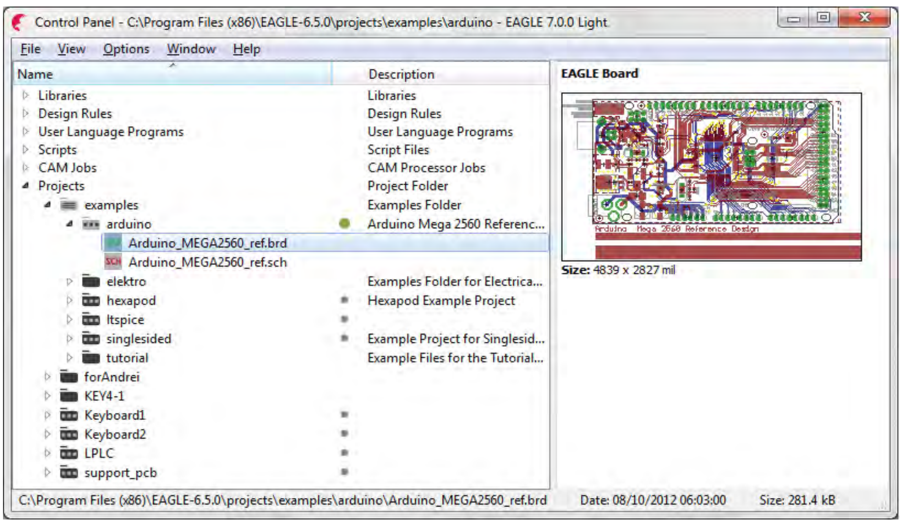


Fig.2. Control panel

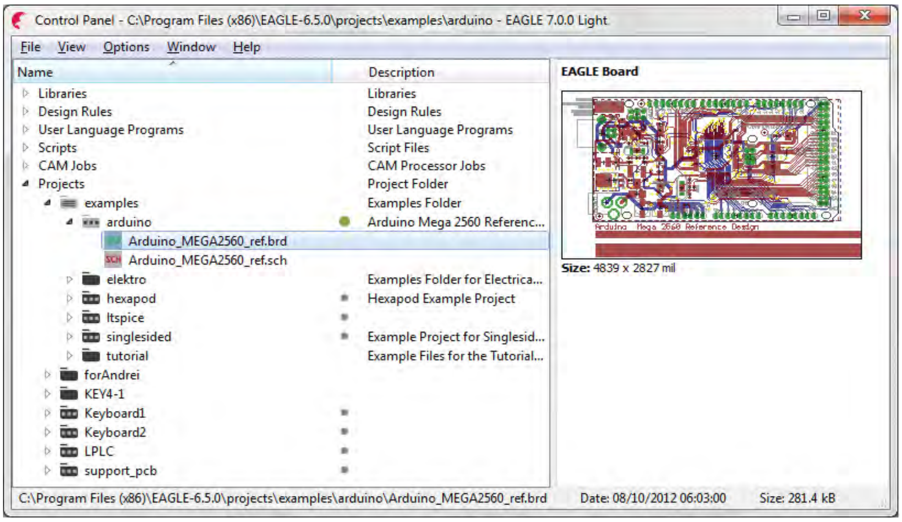


Fig.3. Schematic entry dialog

Projects

This is where your projects are organised, in a directory style listing. Navigate through this list to find and then open your design.

Designing a board

We've introduced several new concepts, so let's just recap, and fill in some details. When you design a board, you start by creating a new project – in essence, a new directory for you design files. If you right-click over the word 'Projects' in the list on the left, you will find the option for 'New Project'. Click on that, and enter the name 'SENSOR'. Now right-click on the name SENSOR, and select new->Schematic. A new schematic dialog will appear, as shown in Fig.3.

This dialog window is where we will enter the circuit diagram of our board. Typically, one enters the complete circuit diagram *before* switching to the board design, but it's not essential. Sometimes one will draw a bit of the schematic, play with the layout of the components on the board, and then go back to the schematic. It's normal, however, to enter the schematic details and then layout the board. The schematic is the design; the board layout is just the physical representation – and some PCB programs even allow for multiple board designs for the same schematic. EagleCAD does not.

A word from the wise: once you have started creating the board layout, *always* have both the schematic and the board dialog windows open while you make changes. For some reason, making changes in one drawing while the other is closed can cause a loss of synchronisation between the two. It's fine, however, if you have both open, and minimise the one you are not using at the moment.

We are going to finish with EagleCAD for this month, so close all three windows, the order in which you do so is not important.

We have decided on a PCB design; it's actually going to be two boards: one very small and simple, using pre-installed components and designed so we can manufacture it at home; the second, more involved, using surface-mount components and requiring a solder stencil for volume manufacturer.

Next month

In the third part of this series we start with the simple PCB design, and show how you can convert the PC-based design into a hand-built board.

NET WORK

by Alan Winstanley

The connected home

THANKS to a bulging array of Internet-aware systems coming to market, the home appliance industry is grappling with the new technologies that will allow consumers to use their smartphone or tablet to control a wide range of domestic devices connecting wirelessly to the cloud. In previous *Net Work* columns I introduced the Crock-Pot Smart Slow Cooker (April '14 *EPE*) and Philips' Hue Wi-Fi LED lights (May '14 *EPE*) as examples of smart devices that are controlled with dedicated apps. The Samsung Smart Home (March '14 *EPE*) points to the future as Samsung sees it, with network appliances connected to a cloud and controllable with mobile devices. Samsung's Home View would use an appliance's built-in IP camera to provide security coverage of the next-generation home.

Last month, in September's issue, I highlighted a rival range of intelligent electrical appliances from South Korea's LG. Their 'HomeChat' fridge, microwave and washing machine can be interrogated via a Messenger-style conversation using an app. The LG HomeChat fridge contains a camera that photographs the fridge contents every time the door is opened, intended to help busy families manage their grocery shopping lists. In fact, the idea of a smart fridge camera is not new: in 2012 German maker Bosch-Siemens (BSH) also floated the concept of a 'House of Innovations' featuring their new 'Home Connect' protocol that would control an oven, cooker and cooker hood, even a coffee machine, via an app that provides simple monitoring or remote control over a home-based network. A prototype fridge containing two cameras was also shown by Siemens. Add in GPS and you have an appliance that knows how hard the water is in the customer's locality, so it sets up a dishwasher's water softener automatically. Also suggested was a small home projector running on the same network that allows recipes and suggestions to be displayed on a kitchen work surface, for example.

Bosch-Siemens has been in no hurry to rush smart appliances to market until the technology is right and BSH is at pains to proclaim the open nature of the Siemens Home Connect protocol. As a result, Home Connect could eventually control other brands of gadget that are compatible with the same protocol, says BSH who are forming a separate company to handle this emerging technology. Customer product support could also be provided direct via live video chat. Taking responsibility and supporting a product this way can only be good for customer retention, and is much better than enduring mindless call centres or chasing spares, but it will probably still result in expensive call-outs should things go wrong. A new-generation appliance could send an error message over IP to help with diagnostics before the repairman visits.

An iOS app for tablets and phones will spearhead the new Home Connect concept and an Android app would be available in 2015, say BSH. A wireless router is needed and as we enter a world where home networks could be hacked through a Smart TV or an insecure home router, Siemens states that it will use certified levels of security and that end-user data will be stored anonymously on their own cloud-based servers.

Making a Nest

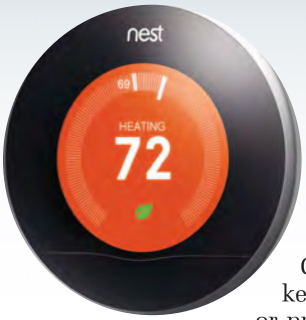
A well-worn mantra in the commercial world states that if you don't have the technology, simply buy it from somebody who has. Nest Labs Inc. (**www.nest.com**) is an interesting maker of smart home thermostats and smoke alarms that Google bought for $3.2 billion in cash early this year. Nest's Learning Thermostat is a wall-mounted dial with colour screen that learns your usage trends over time to help you conserve energy and reduce your heating or air-conditioning bills. Nest is also controllable from an app to allow monitoring remotely, and using its Wi-Fi connection it integrates with weather conditions and forecasts, so that it learns how you use your heating or aircon in response to the prevailing weather. A YouTube trailer at **https://www.youtube.com/watch?v=L8TkhHgkBsg** shows the basics.

Protect your Nest

Nest also produces a new-generation smart smoke and CO alarm called Nest Protect. Nest offers a powerful argument for adopting new intelligent detectors like these. For example, like many, the author is guilty of being awoken in the night

Home Connect from Bosch-Siemens will control compatible appliances over the network

Home Connect could eventually operate other brands of appliance and offer more services to users



Nest's Learning Thermostat is wireless and provides control via an app and energy usage data

due to a smoke alarm 'chirruping' in low-battery mode somewhere in the house, and dealing with it by disconnecting the battery before shuffling back to bed again. Checking them periodically involves keeping one eye on a blinking LED or pressing the test button once a week, which none of us ever does. And having several detectors around the house, locating a troublesome chirruping smoke alarm is another problem.

The Nest Protect is different from traditional smoke and CO alarms in every way: it broadcasts warnings of smoke or carbon monoxide in plain English (and according to the trailer, the UK version of Nest has a proper English accent – no Speak 'n Spell American voices here), and the system announces the location of the hazard which you pre-programme during setup. When carbon monoxide is detected, it also warns you in English to move to fresh air. Early warnings of potential problems, as well as emergency situations are duly announced, and the system can be hushed, too – ideal near the kitchen toaster. It's backed up with an 85dB horn, plus Android and iOS apps are also used for alerts. The Wi-Fi smoke alarm detects ambient light and motion and also lights the way at night, and self-tests itself constantly. Should the Wi-Fi go down then multiple units can communicate with each other via their own personal area network based on 802.15.4, another emerging trend in networking technology.

By sharing basic Nest data with Google itself (eg, whether a user is at home or not), this opens up the prospect of greater integration with Google's own applications which could automate certain tasks: if someone's half a mile away and heading home (detected by a geofence) then the heating could be turned up or the garage doors could be opened in readiness. Voice recognition control via Google's servers is also likely. Google's involvement with Nest is likely to raise privacy issues when Nest user data is shared with the advertising giant this way. Battery (six AA Lithium Ultimate, multi-year life) or mains wired versions (with battery backup) of Nest Protect each retail at £89. This ceiling-mounted safety device has already started to appear in UK DIY stores (B&Q) as well as Apple Stores, John Lewis and Amazon, and I intend to install them in my home as a matter of course.

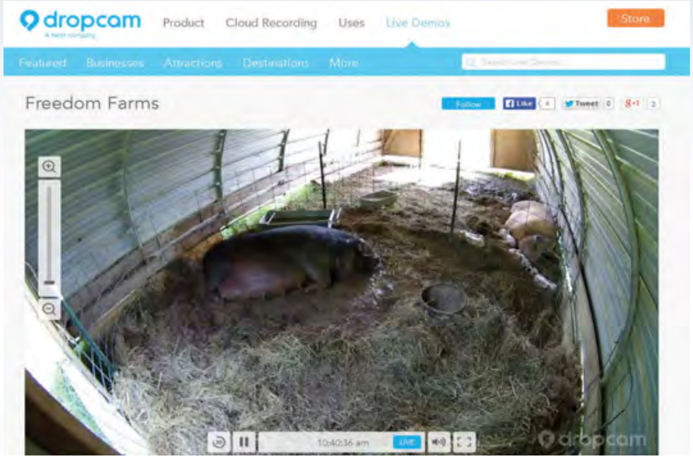
Nest Protect is a network-ready wireless smoke and carbon monoxide alarm with spoken English warnings and multiple sensors (battery or mains)

Watch your Nest

With Google's blessing, Nest has in turn snapped up the smart camera firm Dropcam for $555 million as Google squares up to meet the demand for an estimated 25 billion future devices that will comprise the 'Internet of Things' or 'IoT'. Dropcam's range of IP cameras helps with security and baby monitoring, featuring HD, two-way sound, alerts for motion or sound, night vision and optional cloud-based video recording. Apps for Android and iOS are available. A lovely demonstration of Dropcam with sound at **https://www.dropcam.com/live-demos/attractions/freedom-farms** showed us inside a US-based piggery with an expectant (and very grumpy!) sow called Princess snuffling around in the mud, with a delivery of piglets eagerly awaited by all looking in. The cloud recorder enables the clock to be wound back to review earlier footage. Even on rural ADSL the video feed was reasonably good with little time lag. The HD Dropcam is typically £150 and the 'Pro' is £199 ($149 or $199) but the cloud recording service is an extra annual cost.

Forging alliances

As the IoT evolves rapidly, alliances are forming among software and hardware manufacturers as they try to create



Happy as a pig in mud: this Dropcam live demo (with sound) of an expectant sow demonstrated their IP cameras perfectly. More news of the litter next month!

the de facto standard for appliance control. The Internet of Things could face its own VHS/Betamax or Homeplug/Homegrid contest all over again.

Starting in no particular order, the Allseen Alliance oversees the AllJoyn Open Source project (**https://www.alljoyn.org**) which strives to set interoperability standards across networks in home, office and automotive applications. Its members include Qualcomm, Microsoft, LG, HTC, Cisco, TP-Link, Symantec, Lite-On and many more. The competing Open Interconnect Consortium (**www.openinterconnect.org**) wants to deliver an open source interconnectivity solution of its own, backed by Intel, Atmel, Dell, Broadcom and Samsung. If that's not enough, the Thread Group (**http://threadgroup.org**) is focussed on home devices that will inherently have low power battery operation and use an 802.15.4 personal area network: devices talking among themselves as well as with a router. Samsung has a foot in this camp, as do Nest, ARM and Yale Security, which alludes to the production of intelligent, networkable home security solutions in the future.

Apple, meantime, is pushing Homekit (**https://developer.apple.com/homekit**) which supports Apple's Home Automation Protocol. Apple's Siri speech recognition system will integrate with this to offer voice control of connected devices. Partners include Honeywell, which will be producing its own network-aware thermostat to rival Nest, called Lyric. Philips is expected to support Apple's Homekit with its Hue LED lights (reviewed in May '14 *Net Work*).

All of this depends on a user's wireless connectivity to the manufacturer's cloud. So it was at exactly this point in writing my copy, readers, that my mains electricity suddenly went off. My PC's uninterruptible power supply kept things running for a few minutes, while I scrambled to save my work before I delved into the household fusebox. An RCD (GFCI) had tripped and taken half the household electricity with it, and eventually I pinpointed the washing machine as the culprit. As Mrs W confirmed, as soon as it started to fill, at the point that the drum should start to turn, the electrics blacked out again. My engineer colleague suggests the motor or controller board shorting to earth and spares could be more than the machine was worth. Perhaps a new Internet-aware smart washer would generate a helpful diagnostics code, except the outage took out my wireless router as well, thereby downing my home network entirely. Never was the saying 'The more things change, the more they stay the same' more true.

That's all for this month's *Net Work* – it has been great to bring you news of forthcoming Internet developments and some really exciting devices are queuing up to burst onto the market, so rest assured *Net Work* will keep you posted. You can email the author at **alan@epemag.demon.co.uk**

INTERFACE

By Robert Penfold

Counting, timing and frequency

THE previous *Interface* article covered some simple ways of timing external events using a Raspberry Pi computer, a Python program, and a small amount of hardware on the computer's GPIO port. We start this time in a similar vein, with simple hardware and software for timing and counting applications. For example, this system could be used as a lap counter and timer for a model racing car set. Obviously some form of sensor is needed to detect the car passing the Start/Finish line, but this is not an aspect of things that will be covered in detail here. Various types of sensor (eg, optical) have been covered in recent *Interface* articles, and at least one of these should be suitable for most applications. Something as basic as a micro-switch is often sufficient, and it is worth considering simple solutions before jumping in with more exotic approaches.

Bouncing back

One common problem when using a mechanical switch as a sensor is that of 'contact bounce'. This is where the switch does not open and close cleanly, but instead produces two or more pulses in rapid succession each time it is operated. In a counting application this can result in the count being incremented by more than one each time the sensor switch is activated. In an extreme case, the count can increment in dozens rather than one at a time. It is not only mechanical switches that can cause this problem, and it can easily occur with other types of sensor, such as optical ones. In fact, it is quite likely to occur if an optical sensor is detecting something that has a complex shape, which would probably include most model racing cars.

A Schmitt trigger at the output of a sensor will occasionally cure problems with contact bounce and the like, but it will often just result in bursts of 'cleaner' output pulses with less noise, rather than a single output pulse. The more reliable solution is to use a monostable circuit. When triggered, this type of circuit produces an output pulse that has its duration set by a C-R timing network. The basic idea is to have the duration of the output pulse greater than the overall duration of the output pulses from the sensor. Any extra transitions from the sensor will then be ignored, because the monostable will already be in the triggered state when they occur.

A simple monostable circuit based on a 555 timer is all that is needed in the current context, and a suitable circuit is shown in Fig.1. IC1 is the 555 timer chip; here, it is actually a low-power version of the 555. It will operate on the 3.3V supply available from the Raspberry Pi's GPIO port, which means that its output can directly drive an input of the port without any problems. In this case, it is used to drive GPIO 7 at pin 26 of the port. The output at pin 3 of IC1 is normally low, and it pulses high when the circuit is triggered.

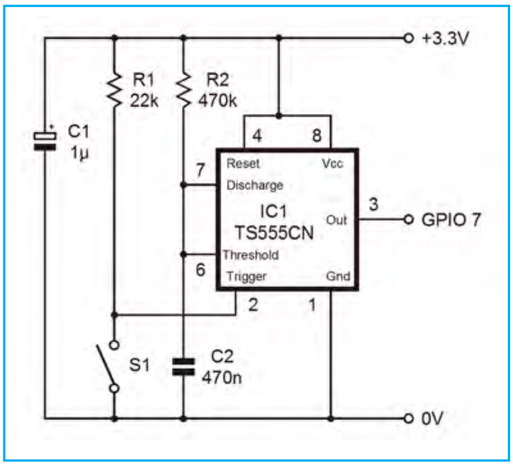


Fig.1. A simple 'debouncing' circuit based on a 555 timer chip used in monostable mode. S1 is the sensor switch, and would normally be a micro or reed switch

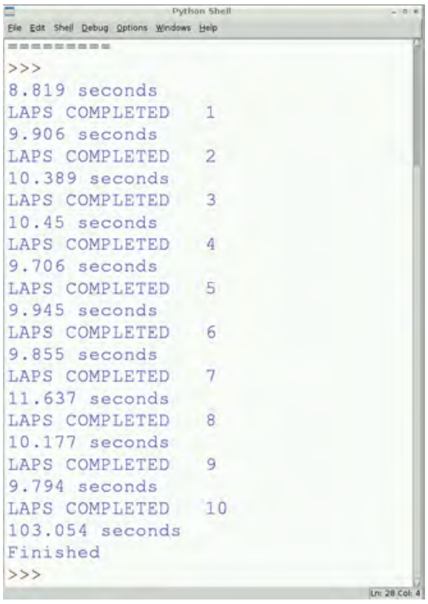
Resistor R2 and Capacitor C2 are the timing components of the monostable, and the output pulse duration is approximately 1.1CR seconds. The specified values produce an output pulse duration of about 243ms (milliseconds). These values represent a good starting point, but they may need to be altered. The correct pulse duration for a monostable in this type of application will vary depending on the precise nature of the sensor. The switch or other signal source will normally produce a short pulse as the detected object passes by. The output pulse from the monostable must be comfortably longer than the output signal from the sensor so that multiple triggering is avoided. On the other hand, it must not be so long that the monostable is not triggered the next time a passing object is detected. There is usually plenty of latitude here, and a little experimentation should soon determine suitable values for C2 and R2.

The monostable is triggered by a falling edge on pin 2 of IC1. R1 normally holds pin 2 high, but it is pulled low when sensor switch S1 closes, and the monostable is then triggered. Pin 2 can, of course, be driven from an electronic sensor of some kind, but bear in mind that it is operating from a 3.3V supply, and therefore needs to be driven at 3.3V logic levels. R1 and S1 are not needed if the circuit is driven from an electronic sensor, or R1 can remain and the circuit can be driven from an open-collector output. This method effectively provides level shifting if the circuit is driven by a sensor that operates at normal 5V logic levels, and ensures that IC1 will not be damaged.

Counter software

Listing 1 is for a simple Python 3 program that provides timing and counting. It provides individual lap times and a total time once ten laps have been completed. The overall timing is handled by a routine that is essentially the same as the one featured in timer software for the previous *Interface* article. Additionally, this software has a `while… loop` that counts the number of laps and brings thing to a halt once the appropriate number have been completed. An additional timing routine within the loop provides the individual lap times. The variable called `Laps` is given an initial value of `0`, and it is incremented by one on each loop of the program. The `while… loop` continues while `Laps` is less than `10`, and the value used here sets the number of laps that are counted before the program is brought to a halt. This can be altered to halt things after any desired number of laps.

The program waits for a rising edge from the monostable on GPIO 7 before entering the loop. In a lap counter application, the program is waiting for the car to cross the Start line and get things under way. Once into the loop, a time is taken and is placed in the variable called `lapstart`, and the program then waits for another rising edge on GPIO 7. When this is detected, another reading is taken from the timer, and it is placed in the variable called `lapend`. The lap time is then calculated from the two readings and is printed on the screen. This process



```
Python Shell
File Edit Shell Debug Options Windows Help
=========
>>>
8.819 seconds
LAPS COMPLETED    1
9.906 seconds
LAPS COMPLETED    2
10.389 seconds
LAPS COMPLETED    3
10.45 seconds
LAPS COMPLETED    4
9.706 seconds
LAPS COMPLETED    5
9.945 seconds
LAPS COMPLETED    6
9.855 seconds
LAPS COMPLETED    7
11.637 seconds
LAPS COMPLETED    8
10.177 seconds
LAPS COMPLETED    9
9.794 seconds
LAPS COMPLETED    10
103.054 seconds
Finished
>>>
```

Fig.2. The readout on the screen after the completion of ten laps

is repeated until the loop reaches its end point and is exited. The overall time is then calculated and printed on the screen. This produces something like Fig.2 on the screen.

Due to the fact that the various components of the program operate less than instantly, it is likely that there will be a discrepancy between the total for the individual lap times and the overall time produced by the program. In particular, the printing to the screen is not particularly fast and could produce slight slippage. It would probably be possible to produce a more efficient version of the program, but it does at least provide a useful starting point.

Time to frequency

It is possible to measure frequency by first measuring the duration of one cycle, and then dividing one by the time in seconds to give a frequency in hertz (Hz). This method is certainly possible using the GPIO port and the Python timing facilities, but it does not work very well in practice. The problem is that the timer only gives millisecond resolution, and the true accuracy seems to be rather less than this degree of resolution would suggest. It is possible to measure frequency, but only at the lower end of the audio range and into the infra-audio range.

High frequencies can be handled with the aid of prescaling. This is where the input frequency is divided by some additional hardware to give a lower frequency that the frequency meter can accommodate. In this case, dividing the input frequency by 1000 extends the upper limit of the system so that middle and high audio frequencies can be measured. Fig.3 shows the circuit diagram for a three-stage divider circuit that divides the input frequency by 1000. It requires input pulses at suitable logic levels, and some signal conditioning circuitry ahead of the input would be needed for operation with pulses at the wrong levels, or sine waves and other non-pulsed signals.

The divider is based on three 4017BE CMOS '1 of 10 decoder' chips, which require the standard anti-static handling precautions. In this circuit (Fig.3), the ten outputs of the decoder section are unused. It is only the straightforward divided-by-ten output signal from the Carry Out output (pin 12) that is used. The 4017BE has a Reset input at pin 15 and a Clock Inhibit input at pin 13. These are not needed in the current application, and are connected to the 0V supply so that the divider circuits can function normally. In addition to the divided by 1000 signal, outputs at one tenth and one hundredth of the input frequency are available from pin 12 of IC1 and IC2 respectively.

The software for the frequency meter is provided in Listing 2. When the program is run, it measures the time between the first two rising edges that are detected on the GPIO 7 pin. This gives the duration of one input cycle, or what is actually one thousand cycles when the prescaler is used. To find the frequency (the reciprocal), one is divided by the measured time, and this value is then multiplied by 1000 to give a frequency in hertz. This figure is then printed on the screen.

It should be noted that with this method of frequency measurement the time taken for a reading to be completed varies in proportion to the input frequency. It is only about half a tenth of a second or so with an input frequency of 10kHz, but it is over 10s with an input frequency of 100Hz. The resolution and accuracy obtained with a simple system such as this is not going to rival that of a dedicated digital frequency meter. It provides results more in line with a simple analogue frequency meter, but if nothing else, it is an interesting experiment to try.

With both timing and frequency measurements there seem to be slight inconsistencies that prevent true one-millisecond accuracy from being obtained. Using interrupts helps to ensure that the software responds very rapidly to signals on the input lines, but there will be other services using interrupts, and it is likely that most of these have a higher priority than the GPIO lines. This could result in slight and variable delays being introduced. Anyway, the results are perfectly adequate where slightly less than millisecond accuracy will suffice.

Listing 1

```
iimport RPi.GPIO as GPIO
import timeit
GPIO.setmode(GPIO.BOARD)
GPIO.setwarnings(False)
GPIO.setup(26, GPIO.IN)
Laps = 0
GPIO.wait_for_edge(26, GPIO.RISING)
start = timeit.default_timer()

while(Laps < 10):
    lapstart = timeit.default_timer()
    GPIO.wait_for_edge(26, GPIO.RISING)
    lapend = timeit.default_timer()
    lapsecs = lapend - lapstart
    millisec = lapsecs * 1000
    millisec = int(millisec)
    lapsecs = millisec/1000
    print (lapsecs, "seconds")
    Laps = Laps + 1
    print ("LAPS COMPLETED  ",Laps)

end = timeit.default_timer()
secs = end - start
millisec = secs * 1000
millisec = int(millisec)
secs = millisec/1000
print (secs, "seconds")
GPIO.cleanup()
print ("Finished")
```

Listing 2

```
import RPi.GPIO as GPIO
import timeit
GPIO.setmode(GPIO.BOARD)
GPIO.setwarnings(False)
GPIO.setup(26, GPIO.IN)
GPIO.wait_for_edge(26, GPIO.RISING)
start = timeit.default_timer()
GPIO.wait_for_edge(26, GPIO.RISING)
end = timeit.default_timer()
secs = end - start
millisec = secs * 1000
millisec = int(millisec)
secs = millisec/1000
print (secs, "seconds")
frequency = 1/secs
print (frequency * 1000, " Hertz")
GPIO.cleanup()
print ("Finished")
```

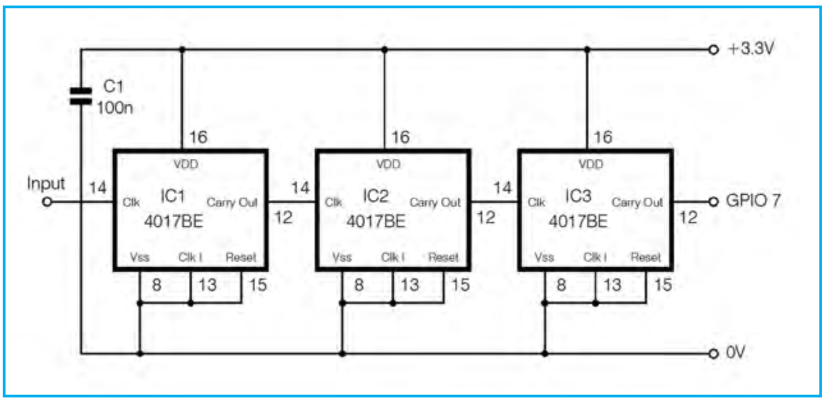


Fig.3. A divide-by-1000 prescaler circuit using a series of three 4017BE one-of-ten decoder chips. The ten outputs of the decoder are unused here, and only the Carry Out outputs are used

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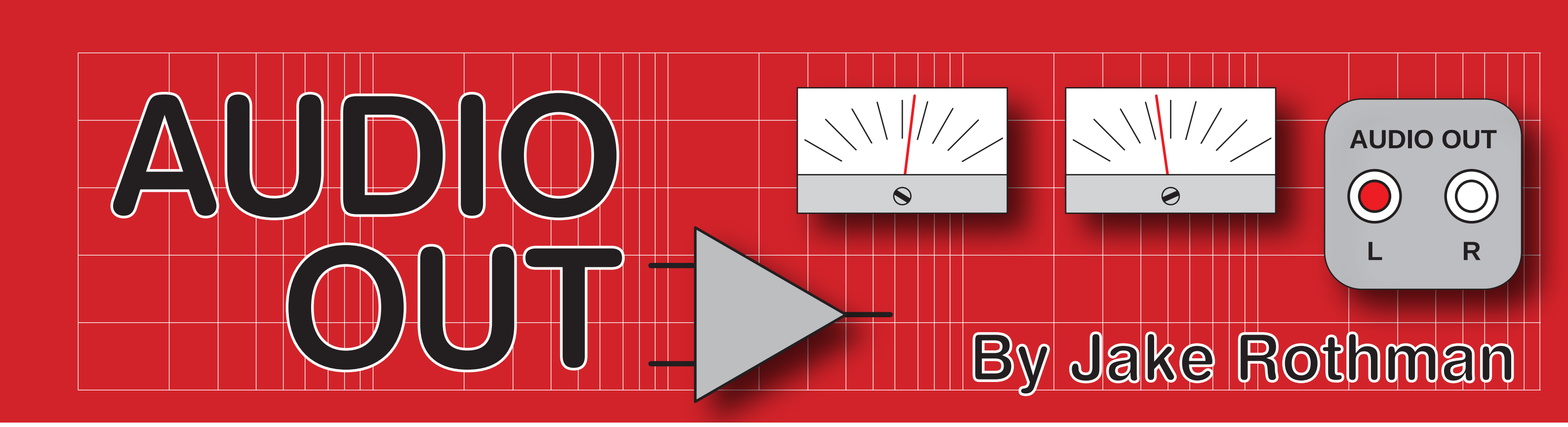

Eradicating wet electrolytic capacitors from audio circuits – Part 3

Non-electrolytic electrolytic capacitors

While researching capacitors, component manufacturer AVX put me in touch with their applications team manager, Dr Tomas Zednicek, who has contributed to 25 scientific papers describing the physics of tantalum capacitors. It turns out solid tantalum and polymer capacitors are not electrolytic capacitors at all. The term 'solid-electrolyte electrolytic capacitor' is a misnomer that has arisen because they are used in the same situations as normal wet electrolytic capacitors and are generally polarised. Also, when solid capacitors are manufactured, the oxide dielectric is initially formed by electrolysis.

The MIS structure – a distortion mechanism?

Solid capacitors have a metal-insulator-semiconductor or MIS structure, not the metal-insulator-metal structure of normal capacitors. It is usually in the form of tantalum-tantalum pentoxide-manganese dioxide, as shown in the diagram (Fig.1). There are variations, such as solid-aluminium, niobium, and types where the manganese dioxide is replaced by lower-resistance polymers, but the MIS structure remains. This exhibits subtle potential-barrier / depletion-region effects, due to the different energy band gaps of the materials. In addition to this, there are the asymmetric leakage currents that all polarised capacitors possess. It is likely that modulation of the depletion region's width with signal gives the increased distortion. The MIS structure can be thought of as similar to a metal-oxide rectifier diode with a massive capacitance. Dr Zednicek suggests that to avoid these effects, it's best to keep the applied signal voltage to less than 1V with zero DC bias. In many audio situations it could hit up to 20V. It appears the distortion is inherent in the physics of the device and it is still not fully understood.

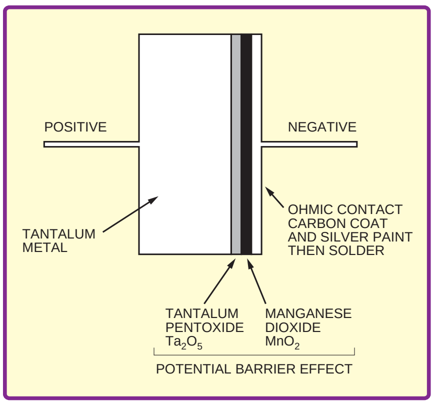

Fig.1. The metal-insulator-semiconductor (MIS) structure of a solid-tantalum capacitor. The small potential barriers between these layers cause distortion

I did an experiment where I sandwiched a piece of manganese-dioxide-impregnated fibreglass from an old Philips SAL capacitor between two neodymium magnets, illustrated in Fig.2. I then hooked it up to a power supply, varied the voltage and measured the current. It was pretty non-linear, as the graph in Fig.3 shows. Connecting up the manganese dioxide 'resistor' to a signal generator set to a triangle wave (Fig.4) gave the distorted waveform in Photo 5. Although the interfaces were not the same as in a solid capacitor, it shows where part of the problem lies.

At some point the distortion mechanisms will be better controlled, but we are still stuck with the same basic technology. There is a niobium-oxide polymer capacitor, the OxiCap, that gives the lowest solid-capacitor distortion, but it is still high and worse than in wet electrolytic capcitors. Unfortunately this technology seems to be limited to 10V at present.

Negative feedback

With a few extra components, the capacitors can be incorporated into the negative feedback loop of most audio circuits to reduce their distortion. Since the 'open-loop' distortion of the capacitors is much less than that of the active devices, their distortion can be rendered insignificant.

Fig.2. Set-up to test the conductivity of manganese dioxide, the most common semiconductor used in solid-tantalum capacitors. It consists of two hard-drive magnets clamping a sheet of manganese dioxide from a disassembled capacitor

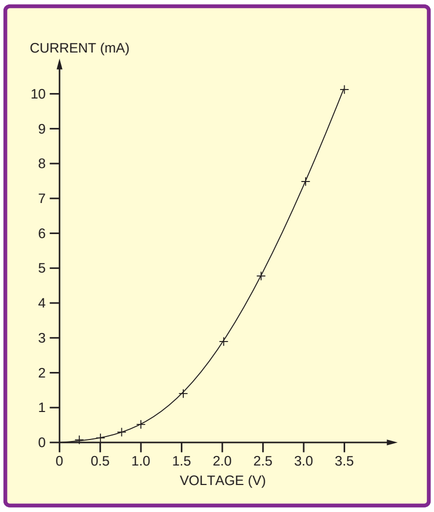

Fig.3. Current against voltage graph of manganese dioxide. It is non-linear, almost exhibiting a rectifying effect

Low frequency or LF instability

When building audio circuits it's a good idea to do checks on LF instability if more than one capacitor is included in the feedback loop. In this situation, the combined phase shifts could hit 180 degrees, at which point what you thought was negative feedback becomes positive feedback. If gain is present then LF oscillation

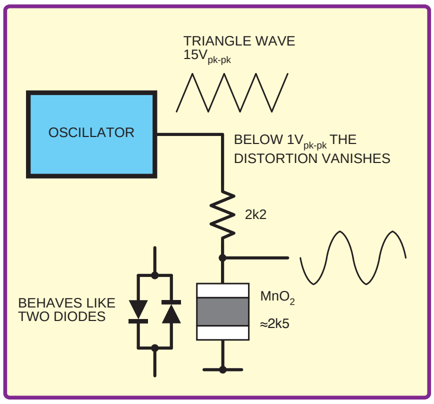

Fig.4. Test set-up showing the manganese dioxide 'resistor' connected to a 'scope and function generator

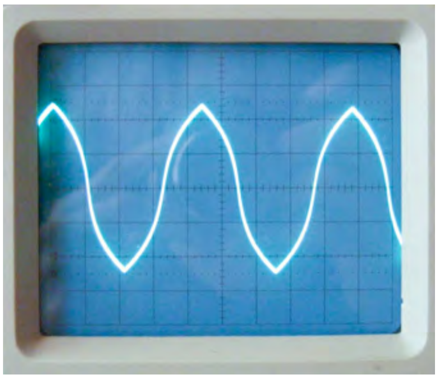

Fig.5. Distorted triangle wave at 15Vpk-pk from test set-up in Fig.4. Below 1V, the signal was undistorted

could occur. This can manifest itself as bouncing on tone bursts and at worst, full-blown 'motor-boating' (low frequency oscillation). Most designers worry about LF instability because in modern DC coupled circuits it is not a consideration, which means they lack experience in dealing with it. For us audio buffs who design valve amplifiers with coupling capacitors and transformers in the feedback loop, it's normal work. Also remember that taking feedback *after* the output capacitor in power-amps can result in high-frequency instability when feeding capacitive loads. I'll cover these stability issues later.

As a taster, here is a standard buffer amplifier (Fig.6) built using ordinary wet electrolytic capacitors. Fig.7 shows the circuit with a modification that uses solid capacitors with distortion cancellation.

Surge capability

Wet electrolytic capacitors have excellent voltage and current surge resistance, they will survive occasional crowbar discharges and short overvoltage pulses, and designers take this for granted. Solid tantalum capacitors can't cope with this. Don't use solid-tantalum capacitors for supply rail decoupling, unless a resistor or slowly ramped power supply is present, since their limited current capability can result in them going short circuit. Where the circuit impedance is above a few tens of ohms, such as for coupling and timing, they are very reliable. The surge problem has led to a general distrust of solid-tantalum capacitors and I have seen a few burnt boards from designers not appreciating this.

This problem is the result of field crystallisation failure; from which aluminium oxide dielectric capacitors don't suffer. The mechanism is a localised heating effect, not unlike secondary breakdown in bipolar transistors. High charge/discharge currents and the resultant heat causes the normally amorphous tantalum pentoxide to crystallise, at localised weak spots. These points are where the MnO_2 layer is thinnest, the lower resistance leading to current concentration. The crystalline form can then breakdown at a voltage below the rating of the capacitor – bang! If

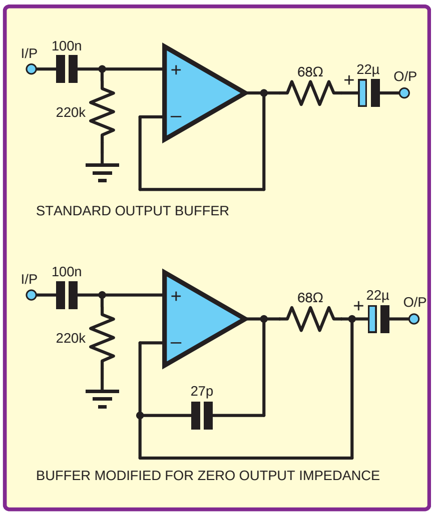

Fig.6. Standard op-amp buffer amplifier using an output electrolytic capacitor. A modification to null the output stabilisation resistor gives zero output impedance to drive long cables

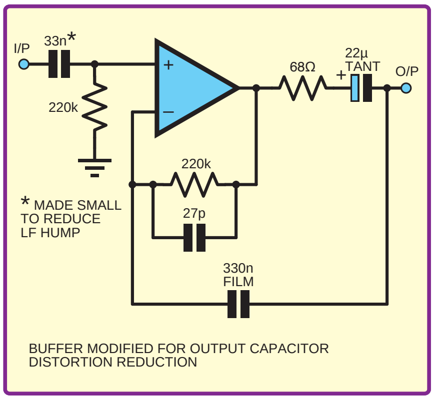

Fig.7. Modified buffer to eliminate distortion from the output capacitor, which is now incorporated in the feedback loop

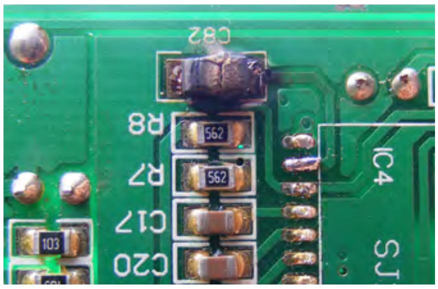

Fig.8. When tantalum capacitors (top centre) fail they go short circuit and can burn. Proper circuit design avoids this

currents are limited, these defect sites can self-heal over time. If not, ignition of the whole capacitor can result, fed by oxygen from the MnO_2 (see Fig.8). This is most commonly seen in higher voltage (>25V) situations. In some designs, series resistors plus circuit source resistance can be used to limit surge currents. The old conservative method was to allow 3Ω/V (ohms per volt), so a capacitor with 20V across it would need to see 60Ω, which would totally ruin the ESR for decoupling purposes. Alternatively, the capacitor can be derated, typically using double the voltage rating required.

Modern tantalum capacitors have seen successive reductions in the required circuit resistance. It was reduced to 1Ω/V in the 1980s and finally to 0.1Ω/V (or a total resistance of 1Ω, whichever is the greater), by around the mid-1990s. This is because the number of defect sites has been reduced by evolutionary improvements. The field failure rate of tantalums dropped rapidly three times from the 1960s up until 1984, where it levelled off for a while. AVX and Kemet now screen their capacitors, since these surge failures occur most often with the first turn-on. If you are using new-old-stock tantalums, it may be a good idea to charge/discharge them before installation in a high surge position. The circuit in Fig.9 uses a 2200µF capacitor charged up to the rated voltage; this blows up any weak capacitor!

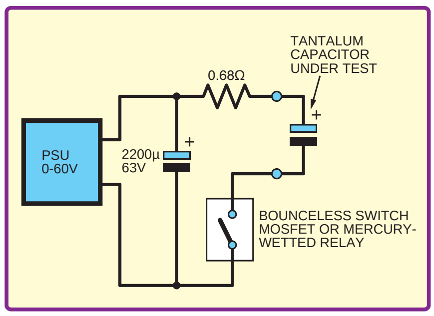

Fig.9. Surge testing circuit for weeding out weak tantalum capacitors from old stock for tough jobs – not normally needed

Fig.10. Philips 122 series solid-aluminium capacitors. These orange 'pearls' are much tougher than tantalum bead capacitors

The best large-value capacitor for power rails and other high-current uses, is solid-polymer aluminium types, which have very low ESR and are very rugged. Even tougher, are the older manganese dioxide solid-Al types, such as the Vishay/Philips 123 series. However, they do have higher ESR than low-ESR wet electrolytic ones. Studer used to use the Philips orange 'pearl' 122 series (Fig.10) and in 30 years I've only ever replaced one – it was installed backwards and lasted two years at –12V!

Interestingly, a high ESR value can be useful when decoupling voltage regulator outputs. This is because the inductive output impedance of all negative feedback stabiliser circuits can resonate with the output capacitor, causing a peak in the output noise frequency spectrum. In audio circuits, 'coloured' noise is much more noticeable than white noise. A resistor added to Zener regulators improves noise filtering, since the source resistance is low. The resistor can also double as a tantalum surge suppressor, see Fig.11.

Avoid the domino effect

It is tempting to rate capacitors for the voltages they are subject to in a correctly functioning circuit. This is often done in consumer equipment. A common problem is that the capacitors may be exposed to full rail voltage under fault conditions. A full amplifier offset, shorted semiconductor or lost additional power rail are frequent causes. The results can be shorted capacitors, damaging the next stage or the loudspeaker. Exploded wet capacitors have also been known to dissolve PCB tracks. I once saw a board that had suffered from a leaking wet tantalum capacitor. These used to use sulphuric-acid-based electrolyte. It looked like a visitation from Geiger's xenomorph from the Alien movies.

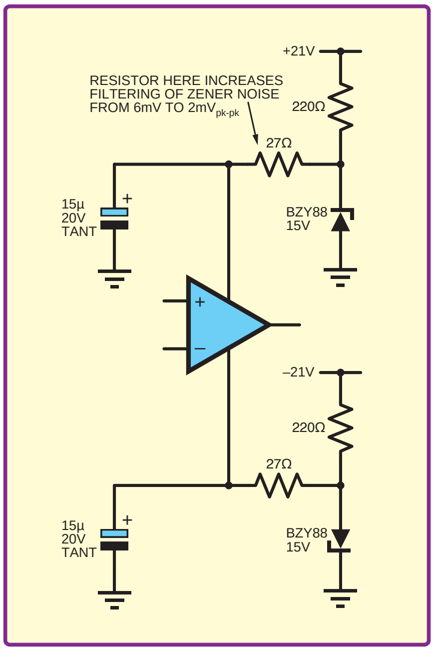

Fig.11. Adding an additional resistor to a Zener diode regulator improves the filtration of Zener noise. Normally the low slope resistance of the Zener and the similar ESR of the capacitor result in poor filtering. The resistor also provides surge protection for the tantalum capacitor. The reduction of regulation is not significant for audio op amp applications

Next month, we'll look at a test-bench amplifier circuit incorporating numerous capacitor tricks.

Circuit Surgery

Regular Clinic

by Ian Bell

Voltage regulation

Recently, there was a discussion on the *EPE Chat Zone* about linear regulated DC power supplies. User ***dave_g*** started the thread, posting a schematic of a 12V, 8A regulated power supply, which suffered from stability problems. Later, ***james*** added another schematic for a supply with a similar specification, pointing out the use of an integrator in the feedback loop, which lead to some debate on what the integrator did and why. Other issues raised included the value required for smoothing capacitors and the level of output voltage drop under high load currents.

All linear regulated power supplies employ negative feedback and so may suffer from instability, although some circuit structures are inherently more stable than others. Next month, we will look at some of the general principles of feedback and stability in regulators, but first we will look at the basics of linear regulated power supply operation, define some of their key characteristics and discuss the choice of smoothing capacitors.

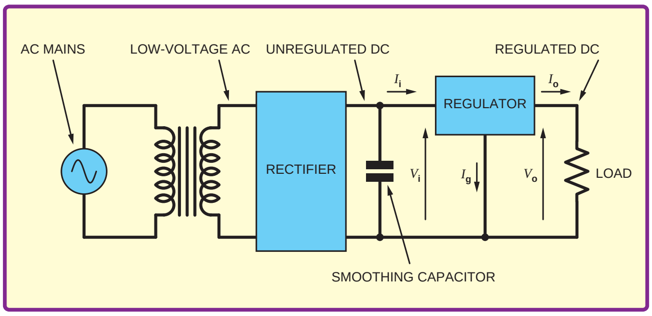

Fig.1. Regulated power supply

Unregulated basics

The structure of a typical regulated power supply is shown in Fig.1. The incoming AC mains supply is stepped down to a lower AC voltage by a transformer. This low voltage AC is converted to DC by a rectifier circuit, which is usually an arrangement of diodes. The raw output from a rectifier is a pulsed waveform, which can be smoothed to a more or less constant voltage by use of a suitable capacitor. The voltage at this point is unregulated, which means that the voltage will vary significantly with current demand.

The unregulated DC provides the input, V_i, to the regulator, whose output voltage, V_o, is ideally constant – the regulator is a feedback control circuit which attempts to keep V_o constant as the load current and input voltage vary. The regulator supplies a current, I_o, to the load, but also requires some current to power its own circuitry. This current, I_g, flows to the regulator's ground connection and is referred to as the ground current. Thus, the total current flowing into the regulator's input, I_i, is larger than I_o by I_g, that is $I_i = I_o + I_g$.

Transform

Mains transformers are specified in RMS (root mean square) voltages and VA power ratings (VA is for volts × amps). The peak voltage of the AC waveform is √2 (square root of 2), or 1.414 times the RMS value, so a transformer with a 12V secondary will output AC with a peak of about 17V. With no load connected, the output voltage is likely to be higher than the specified value.

VA is used instead of 'plain' power (watts) because a transformer connected to a non-resistive load (eg, an inductor, such as a motor winding) has to supply a current which may be larger than that indicated by the actual power used by the load. This is due to the phase shift of the current with respect to the voltage. In such cases the VA rating of the transformer must be larger than the power of the load by a certain factor, depending on the type of load. In simple cases the VA rating can be taken as the power rating, so that dividing the VA rating by the output voltage gives the maximum current. The VA value for the secondary equals that of the primary (more or less, ignoring losses in the transformer). For example, 12V at 8A in the secondary corresponds to 240V at 400mA in the primary for a 240V mains supply.

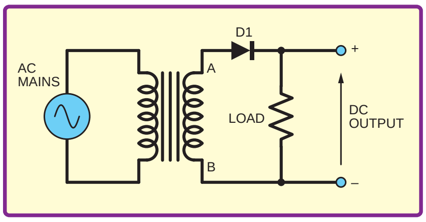

Fig.2. Half-wave rectifier

Rectify

The most basic transformer and rectifier circuit is shown in Fig.2. This only uses one diode and is known as a half-wave rectifier because only half of the AC waveform is involved in producing the DC output. The diode, D1, only conducts in one direction, so current only flows into the load when output A of the transformer is positive with respect to output B. This occurs during one half of the AC cycle, so the load receives a series of half-sine-shaped pulses.

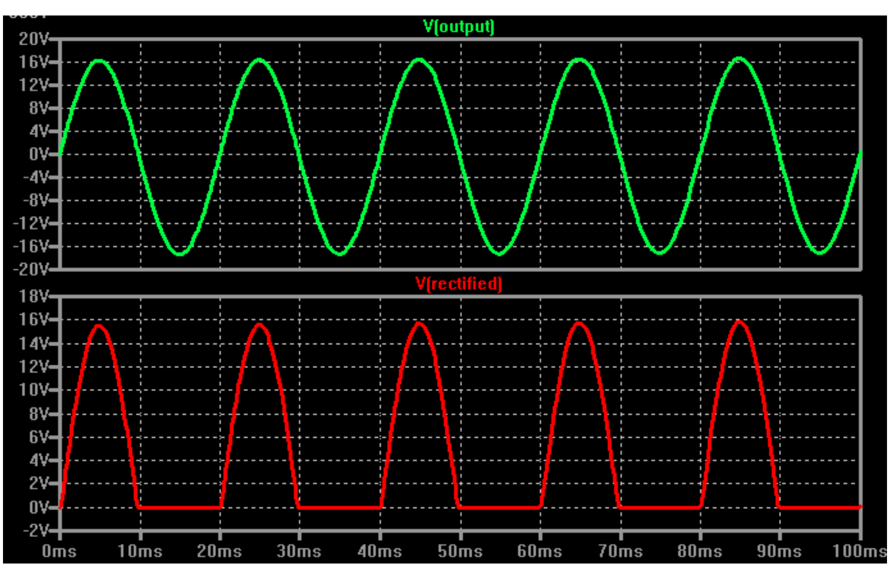

Fig.3. Half-wave rectifier simulation waveforms

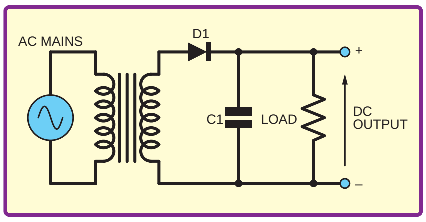

Fig.4. Half-wave rectifier with smoothing

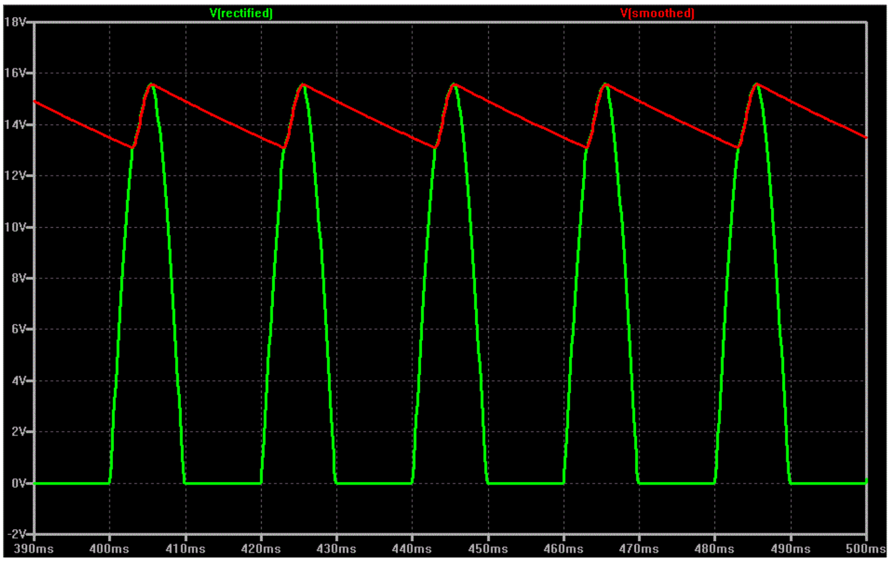

Fig.5. Smoothed waveform from circuit in Fig.4 (red trace) together with unsmoothed output from circuit in Fig.1 (green trace)

Typical rectifier waveforms are shown in Fig.3. The upper (green) trace is the transformer secondary output, and the lower (red trace) is the rectified output. The peak of the rectified pulse is lower than the AC peak voltage due to the voltage drop across the diode. We typically assume a diode voltage drop is about 0.7V, but it may be larger than this (eg, 1V to 2V) in rectifier circuits, particularly at relatively high currents.

Smooth

The circuit in Fig.2 produces a series of pulses – certainly not what we would consider a continuous DC supply. To overcome this we need to store some of the energy from the pulse and release it to the load during the gaps, hopefully keeping the DC voltage nearly constant for a given load current. This is referred to as 'smoothing' and is achieved using a capacitor connected across the rectified output, as shown in Fig.4. Smoothing is not regulation, because the average DC voltage will change with both load current and input voltage. Fig.5 shows the waveforms for Fig.4, with C1=1000µF), superimposed on the original unsmoothed waveform.

The smoothed waveform shown in Fig.5 is much more like DC voltage than the output from the circuit in Fig.2, but it still does not look very smooth. This variation in DC voltage is called ripple and is at the mains frequency for a half-wave circuit. The ripple can be reduced using a full-wave rectifier. This can be achieved by using four diodes in a bridge-rectifier configuration, as shown in Fig.6. However, this is not the only possible full-wave rectifier; for example, it is also possible to use two diodes and a centre-tapped transformer.

For the circuit in Fig.6, on positive half cycles of the mains, when point A is positive with respect to point B, diodes D2 and D3 conduct. On negative half cycles, diodes D1 and D4 conduct. Thus a DC pulse occurs on every half cycle (there are no gaps between pulses, as we saw in Fig.5). After smoothing, the ripple output has twice the frequency of a full-wave circuit (twice the mains frequency). Fig.7 shows the waveforms for the circuit in Fig.6.

The ripple voltage – which is defined as the difference between the maximum and minimum DC output – will increase if the load current increases, or if the capacitor value is reduced. We can estimate the ripple for the half wave circuit using the formula

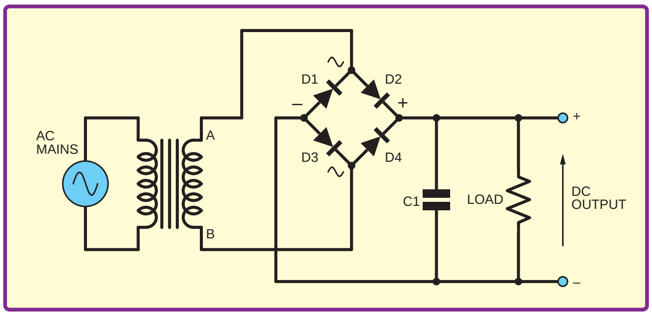

Fig.6. Full-wave bridge rectifier with smoothing

$$V_{ripple(HW)} = \frac{I}{fC}$$

Where I is the average load current (A), f is the mains frequency (Hz) and C is the smoothing capacitor value (F). For example, for the circuit in Fig.4, with a 12V RMS secondary, C1=1000µF, 50Hz, and an average current of around 140mA (14V across 100Ω) the formula gives the ripple as 2.8V. The formula is approximate because it ignores the time the smoothing capacitor spends charging and assumes the discharge is linear (actually it is exponential into a resistive load).

It can be seen by comparing Fig.7 with Fig.5 that the ripple for a full-wave circuit is about half that of the half-wave circuit. This is because the

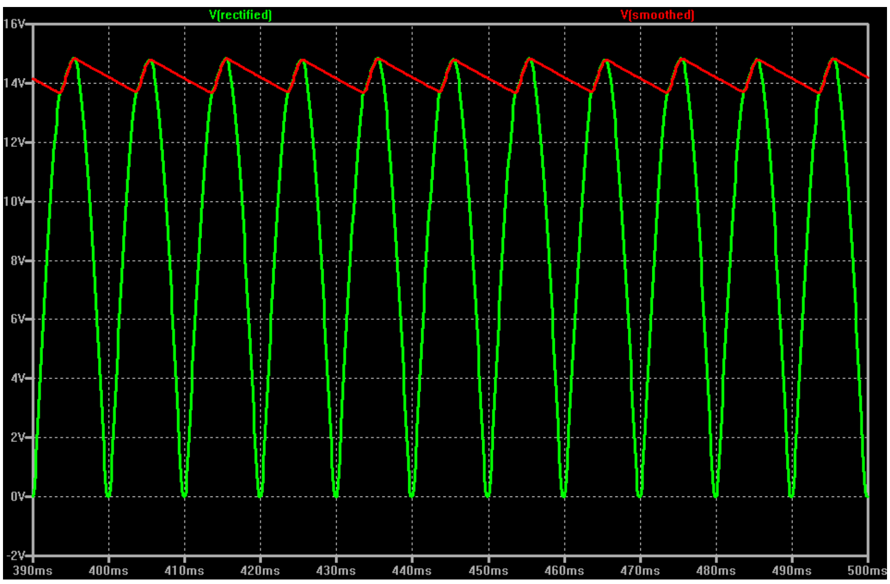

Fig.7. Smoothed (red trace) and unsmoothed (C1 removed, green trace) waveforms for the full-wave rectifier circuit in Fig.6

capacitor discharges for half the time before charging again. The approximate formula for full-wave ripple is:

$$V_{ripple(FW)} = \frac{I}{2fC}$$

There was some discussion about the smoothing capacitors used in the circuits discussed in the *Chat Zone* thread. The specification discussed was I = 8A, using 60Hz mains and a capacitor of 64000µF, which gives a (full-wave) ripple of about 1A. Using a much lower capacitance of 2000µF, the formula gives a ripple value larger than the peak AC voltage (33V as opposed to about 17V peak AV for a 12V transformer secondary). This indicates that a capacitor of this value would fully discharge during the AC half cycle and therefore fail to provide adequate smoothing. The possibility that the 2000µF capacitor may be too small was raised by thread contributors ***james*** and ***armadillo***.

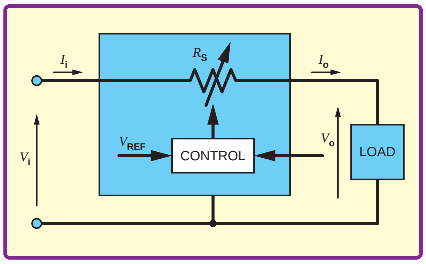

Fig.8. Series regulator concept

Regulating the voltage

For linear series regulators – which is the type of regulator circuit discussed by ***dave_g***, ***james*** and others in the *Chat Zone* thread – the concept of operation is illustrated in Fig.8. The regulator compares the output voltages with an internal fixed reference, V_{ref}, and adjusts the effective series resistance, R_S, between its input and output so that V_o is at the required voltage. For example, if V_i increases with the load constant, then R_S must increase to drop the increased V_i to V_o difference. If the current demanded by the load increases with V_i constant, then R_S must decrease, so the voltage dropped remains the same. In practice, the 'series resistor' (or series element) shown in Fig.8 is a transistor circuit – there are a number of possibilities, but both ***Dave_g*** and ***james*** use P-channel MOSFETs.

With reference to Fig.1 and Fig.8 there are a number of characteristics we can define for series regulators.

Load regulation

If the load current (I_o) varies, V_o should remain constant, but in practice it will vary to some extent. The load regulation can be defined in terms of the ratio of change in V_o (written ΔV_o 'delta V_o') produced by a change in I_o (ΔI_o)

$$\text{Load regulation} = \frac{\Delta V_o}{\Delta I_o}$$

This value is actually a resistance (voltage divided by current), which is the effective output resistance of the regulator (measured in ohms). Load regulation can also be expressed as the change in output voltage (ΔV_o) for some specified change in load current (typically a change from no load to maximum load) divided by the nominal or mean regulated output voltage, V_o.

$$\text{Load regulation} = \frac{\Delta V_o}{V_o}$$

This can be stated as a fractional value (eg, 0.002) or multiplied by 100 to give a per centage (eg, 0.2%).

Line regulation and ripple rejection

If the input voltage (V_i) varies, V_o should remain constant, but in practice it will vary to some extent. The line regulation is defined in terms of the ratio of change in V_o (ΔV_o) produced by a change in V_i (ΔV_i).

$$\text{Line regulation} = \frac{\Delta V_o}{\Delta V_i}$$

This can be stated as a fractional value or percentage. The line regulation can also be expressed as a percentage of the nominal regulated output voltage (V_o), in which case it is defined as follows and measured in %/V (percent per volt).

$$\text{Line regulation} = \frac{\Delta V_o}{V_o \Delta V_i} \times 100$$

At first sight it might seem that line regulation would indicate how well the regulator coped with ripple due to imperfect smoothing of the rectified AC. This is not strictly correct because line regulation is defined for DC conditions – specifically, the implication is that the input is changed by ΔV_i and the regulator has time to fully settle to a new V_o before ΔV_o is measured. For this reason, another parameter – ripple rejection – can be used to characterise how well the regulator avoids passing AC components of its input through to its output.

$$\text{Ripple rejection} = \frac{V_{o,ripple}}{V_{i,ripple}}$$

$$\text{Ripple rejection in dB} = 20\log\left(\frac{V_{o,ripple}}{V_{i,ripple}}\right)$$

Ripple rejection varies with frequency. At low frequencies (probably including the mains frequency) the value will correspond with the line rejection. This is the main concern in our discussion, but ripple rejection typically decreases significantly at high frequencies, which is of importance if a linear regulator is driven from a switching regulator that has high frequency noise on its output.

Line regulation is typically stated as a percentage. For example, if the line regulation was 0.2%, then a 1V input step change would cause an output voltage change of 2mV. Ripple rejection is typically stated in decibels. A regulator with 55dB of ripple rejection would have about 1.8mV of ripple on its output with 1V ripple on its input ($1\text{V}/10^{55/20}$)

Dropout voltage

For the regulator to work, V_i must be larger than V_o, so that some voltage can be dropped over the series element (transistor(s) in a real circuit, R_s in Fig.2). The dropout voltage is the minimum value of V_i at which the regulator functions correctly. For very low V_i, the regulator's output will probably be zero. If V_i is increased from zero, then at some point V_o will typically start to ramp up linearly until V_i reaches the dropout voltage, at which point V_o will stabilise at the regulated value.

A good regulator may be able to have a relatively large amount of ripple on its input voltage and still provide an acceptably small ripple on its output. However, if the ripple waveform takes the input voltage below the regulator's dropout voltage it will no longer regulate and its 'good' ripple rejection capability will no longer apply. Under such conditions the ripple on the output of the regulator may be unacceptably large.

Power dissipation

The regulator dissipates power due to the voltage drop across the series pass element. The power is given by voltage drop times the current:

$$P_D = (V_i - V_o)I_o$$

The ground current will also contribute some power dissipation, but in most cases it will be much smaller than the power dissipated by the series element. We can write the full dissipation as:

$$P_D = (V_i - V_o)I_o + V_i I_g$$

If the input to output voltage difference is large, then a linear regulator can dissipate a lot of power.

Efficiency

The efficiency of the regulator is the ratio between the output power delivered to the load ($P_o = V_o I_o$) and the total power dissipated in the system, which, ignoring the ground current, is:

$$Efficiency = \frac{P_o}{P_o + P_D} =$$

$$\frac{V_o I_o}{V_o I_o + (V_i - V_o) I_o} = \frac{V_o}{V_i}$$

This shows that the closer V_i is to V_o the more efficient the regulator will be. However, remember that this difference must be larger than the dropout voltage. Regulators with relatively small dropout voltages can therefore achieve higher efficiencies, that is, as long as they are operated with their inputs not too far above the dropout voltage.

The term 'low drop out' (LDO) is used for regulators with this characteristic. Use of MOSFETS as the series element (as in the *Chat Zone* circuits) leads to lower drop out than some other common approaches, such as an NPN Darlington circuit. However, LDO regulators are typically more likely to suffer from stability problems and we will discuss stability next month.

PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

Driving an SPI bus colour display

HAVING whetted your appetite for a colour graphics LCD display in the August issue, it's now time to hook one up to our development board and have some fun!

The purpose of this article is to add SPI bus communication capability to our development board template source code, and to show it off by driving a cheap graphics LCD display. Specifically, we are going to recreate the oscilloscope demo first shown in the August issue. This won't be a functioning oscilloscope, just a demonstration of the SPI bus interface and LCD display capabilities. For those of you who are thinking – 'That's a cheat! It's not a real oscilloscope!' – well spotted. We cannot perform any useful measurements without an analogue input, and we will address that over the coming months as we add analogue-to-digital conversion capability; so who knows, perhaps this will become a real oscilloscope!

The LCD we are using is a lovely little 1.8-inch display, running from a single 3V supply with an SPI interface. It has a powerful controller on board, with a RAM buffer for the 160 × 128 colour pixels, each of which can be set to one of 200,0000 colours (although we opted for a simpler 16-bit interface giving 65,000 colours.)

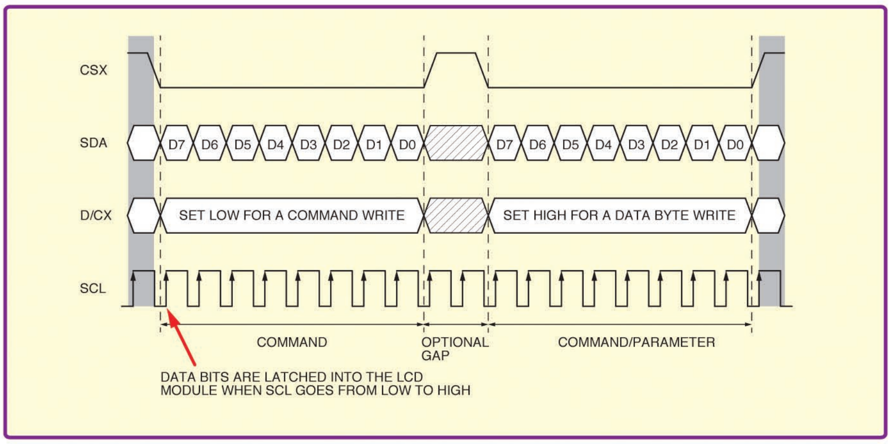

Fig.2. LCD signal timing diagram

On this module, the controller is mounted on a flexible circuit board that is glued to the glass. The flexible circuit board is designed to be heat-bonded to a printed circuit board, a technique obviously beyond most hobbyists. Thankfully, this module comes complete with a carrier board that provides a simple, standard 0.1-inch SIL header – so it fits on a normal breadboard. Ours came from an unknown manufacturer, purchased on eBay. It's still available via the supplier moonriver1980, for just £3.62 including postage and packaging: **http://goo.gl/kM4om4**. A similar (although more expensive) display module can be purchased from Adafruit: **www.adafruit.com/products/358**. We bought ours on eBay, and although the delivery took several weeks, we were happy with the results. Now, let's hook it up to our development board.

Board pinouts – note

With the success of our 'LPLC development board' on Kickstarter, there are now probably more LPLC boards in the wild than handmade *Pic'n'Mix* development boards. From next month, our circuit diagrams and layouts will refer to the development board as 'the LPLC board', and show wiring diagrams based on that board's pin out rather than the original design. They are virtually identical – the only difference is that pins 13 and 14 on the original development board are moved to pins 11 and 12 on the LPLC. Just keep that in mind and you'll be fine. Since the LPC is a professionally manufactured board, it is somewhat more photogenic, and better suited to appearing in the magazine!

So, back to the SPI bus. This month's project is an engineering challenge in two parts: implementing the generic 'driver' routines for the SPI bus protocol, and implementing the SPI-based commands required for the device. The first step is complicated by the fact that the SPI bus specification has a number of operational modes, CPOL and CPHA (based historically on different vendors implementations) allowing for four possible permutations. You can see these in Fig.1.

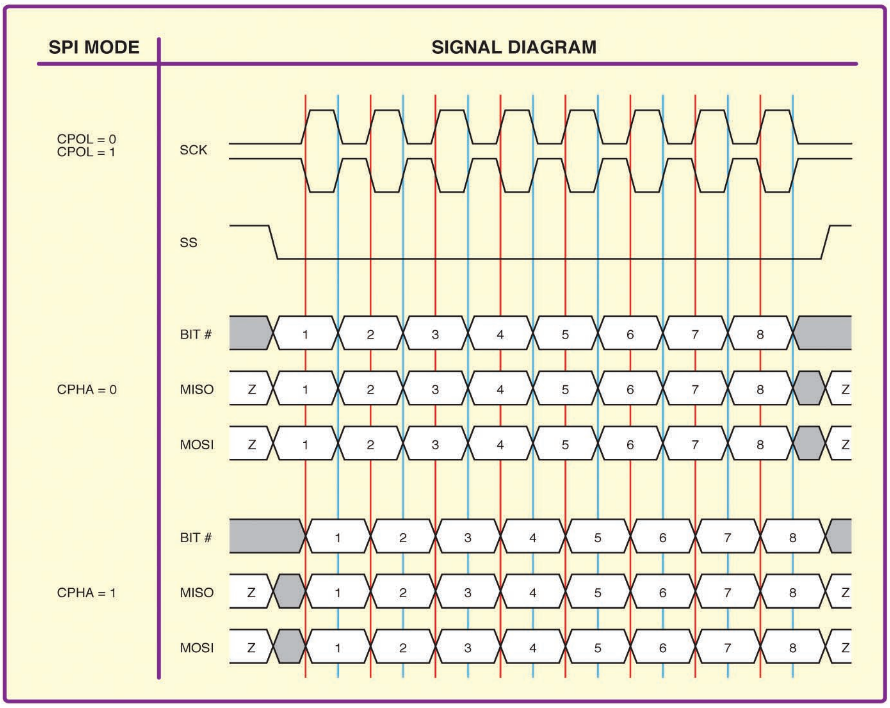

Fig.1. SPI signal timing diagram

SPI bus permutations

CPOL specifies the 'inactive' polarity of the SPI bus clock signal. It also affects whether the microcontroller or slave device reads data bits in when the clock signal changes from 0 to 1 (CPOL=0) or 1 to 0 (CPOL=1).

CPHA specifies the phase of the signal, essentially changing which edge of the clock data bits are read in on when CPHA=1.

So, which permutation do we need for our LCD? Taking a look at the datasheet we find the LCD's timing diagram as shown in Fig.2. We can see that the clock signal (called SCL in this datasheet) starts off low, corresponding to CPOL=0. We can also see that the data bits are latched in on the low-to-high transition, meaning CPHA=0. This is the most common format, so it's no great surprise.

The LCD has eight connections in total (fewer than the simple character LCDs we are used to) as you can see in Fig.3. There are the usual power and ground signals, a separate input for the backlight power and five control signals. These displays have internal voltage regulators, so there is no need for an external contrast resistor, which is a welcome improvement. The days of hooking up and tuning a preset resistor are gone.

The five control signals are as follows:

RESET – Similar to a processor reset signal; puts the LCD controller IC back into a known default state.

SCL – The data clock input signal

SDA – The serial data input signal

D/Cx – Indicates whether the byte to be transferred is a data or command byte

CSx – Chip Select signal, used to remove the chip from the SPI bus, so other devices can talk on it.

These are all standard signals. The RESET and CSx signals are driven from GPIO pins, and the other three can be driven directly by the SPI peripheral on the processor, if you choose to use it.

Peripheral or bit-bash?

We now have a decision to make: do we configure the on-chip SPI bus peripheral to control the LCD, or do we 'roll our own' and bit-bash GPIO pins? Both approaches have their pluses and minuses. If we go with the peripheral, it may run faster, and will consume fewer processor cycles (ie, your processor can do other things while the bytes are being written to the display buffer). If we bit-bash, then we will know *exactly* what the processor is doing to the pins, and we can debug the program more easily.

As this is the first time we have used this LCD module, and it has a complex sequence of byte writes required to initialise it, we will implement the 'bit-bashed' approach. Once we have the display working correctly we can then look at implementing the faster peripheral-based code – but only if necessary. If it works, you might just want to leave well alone.

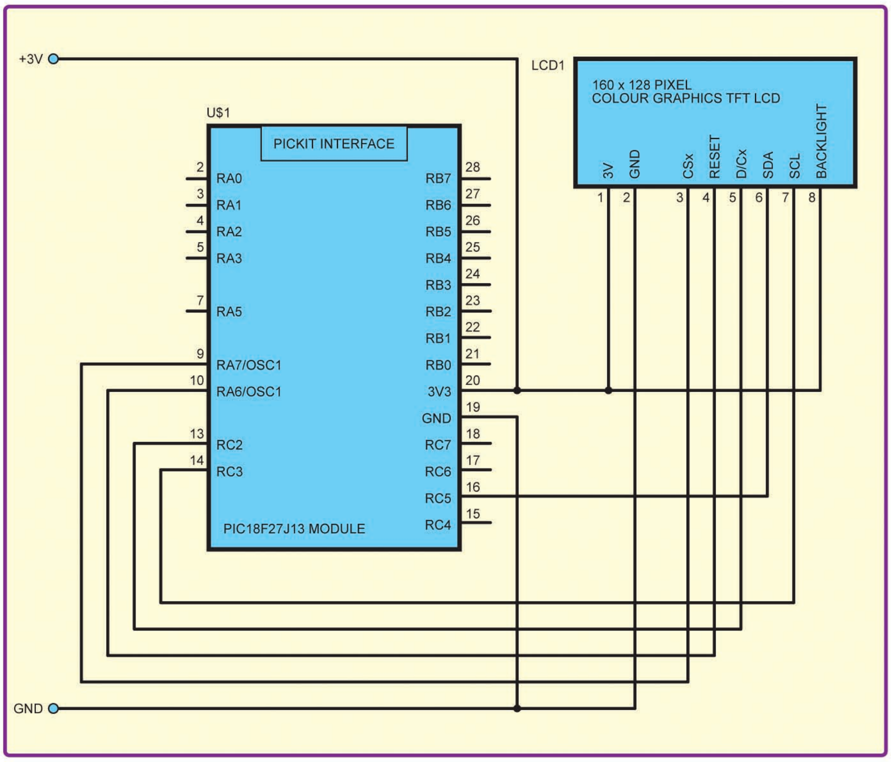

Fig.3. Circuit diagram

Creating the driver

Now we understand how to control the signals to the LCD, let's write the driver, the code module that will be responsible for writing to the LCD. It's called a 'driver' because it 'drives' the signals connected to the LCD. It's normal that a driver will do nothing other than control a particular device. For this reason, we are going to call the source code file that contains the driver code **LCD-Graphic-ST7735s.c**. The name is a bit long-winded, but it makes it very clear what it does – it's a graphics LCD driver, for displays that use the ST7735s controller IC. A similarly named header file, **LCD-Graphic-ST7735s.h**, is included in any of your own 'C' files that use the driver.

The source code for this month's project can be found on the magazine website in the normal location, this month's issue page under: **www.epemag.com/projects.html**. We are going to draw out some of the more interesting points here though. We start with the definition of the pins used to control the LCD (see Code 1 below).

That is another advantage when using a bit-bashed driver; you can choose the pins you use, which can sometimes make a big difference in the layout of a circuit board. Our choice was fairly arbitrary.

The core of the SPI bus driver boils down to the piece of code labelled Code 2 below.

I hope it is obvious that the data byte in variable `da` is having its individual bits, from the most significant bit (0×80) placed onto the serial data signal LCD_SDA, and then the clock

Code 1:

```
#define LCD_CS      LATAbits.LA7 // The chip select signal
#define LCD_AO      LATCbits.LC2 // The Data/Command signal
#define LCD_SDA     LATCbits.LC5 // The data signal
#define LCD_SCK     LATCbits.LC3 // The clock signal
#define LCD_REST    LATAbits.LA6 // The Reset signal
```

Code 2:

```
void LCD_Writ_Bus(unsigned char da)
{
LCD_SDA=(da & 0x80) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
LCD_SDA=(da & 0x40) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
LCD_SDA=(da & 0x20) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
LCD_SDA=(da & 0x10) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
LCD_SDA=(da & 0x08) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
LCD_SDA=(da & 0x04) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
LCD_SDA=(da & 0x02) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
LCD_SDA=(da & 0x01) ? 1 : 0; LCD_SCK = 0; LCD_SCK = 1;
}
```

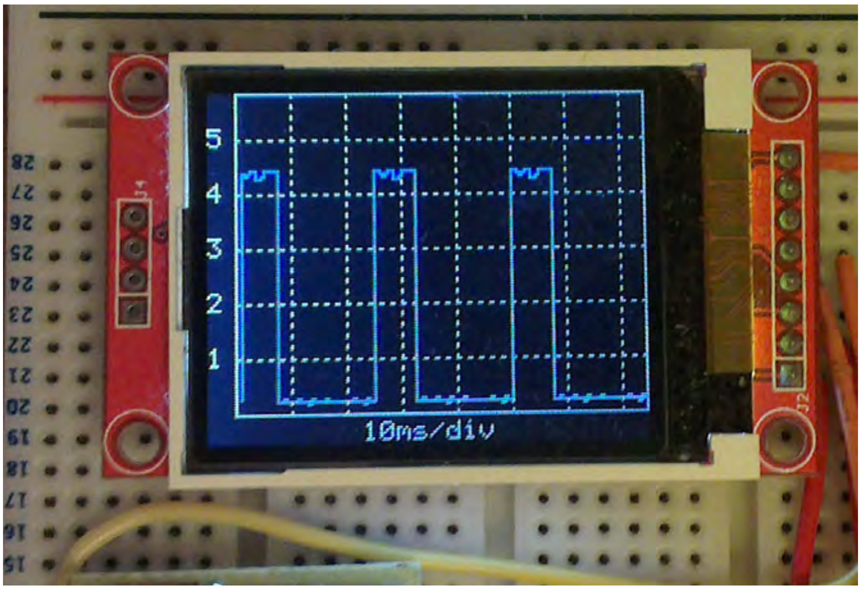

Fig.4. Oscilloscope display

signal is toggled. We run this at the maximum rate possible (ie, there are no extra delays added) as this is still slower than the maximum rate at which the display may be clocked. If we had used the hardware peripheral, we would have needed to be more careful, as our processor would run faster. For now, it's not something we need to worry about.

That essentially completes the SPI driver, at least for writing to the display. Pins have to be configured as outputs and set to the correct default level, but that is straightforward. The more complicated parts lie ahead, however. Initialising the LCD, and writing to the display.

The information about how to use an LCD module comes from two sources: the manufacturer of the controller IC, and the manufacturer of the PCB it is connected to. These are normally two different companies, and the glass itself is manufactured by a third (although as software engineers we rarely need to know about the glass specification.)

LCD modules consist of three main components: the glass, the controller IC (sometimes bonded to the glass itself) and a printed circuit board to which the glass is connected. The PCB provides the power supply, configuration and decoupling components, plus a hobbyist-friendly connector. There is normally a fine pitch connector between the glass and the PCB, which is impossible for hobbyists to use, so the PCB is essential. We look to the PCB manufacturer to tell us what the pinout of the connector is, and we look to the controller IC manufacturer to explain how to use the controller. On our board, the former is printed on the PCB, and the latter is supplied as a 198-page datasheet.

Unreadable datasheets

The datasheet is long, and it's complicated. Probably not an issue if you have written half a dozen LCD drivers this year, but for us hobbyists this is a problem. Thankfully, 'sample code' comes to our rescue. The module manufacturer normally provides sample code, or you can search for code written for the specific controller IC, if you know it. If the module manufacturer does not supply code, and there is no information about the controller IC, you are in trouble – avoid such displays! Ours came with a data sheet and sample code, but we didn't purchase one until we could confirm that code was available from other sources – don't expect the manufacturer to provide code for your specific processor; ours was written for an 8051 processor. Having code from another source gives you the chance to compare approaches, before writing your own. The initialisation sequence required 70 operations, so examples were essential.

Writing to the display is quite simple. A short routine writes the X and Y coordinates to the controller and you then write the 16-bit colour value for that pixel. Line, circle and rectangle primitives were then built upon this principle.

You also need to write your own text routines, if you plan to display text. Unlike the 2×16 character displays we are more used to, these are *graphics* displays and provide no text support at all – your code must include the font for any text you wish to display. On the plus side, you get to choose whatever font you want, and there are plenty available for free on the Internet. We went with the standard 5×7 font for simplicity.

The oscilloscope display shown in Fig.4 was made through a combination of now-standard driver calls, plus a hand created 'image' of the waveform. Hopefully, we will be able to bring this to life in a subsequent article!

Next month

We leave the SPI driver incomplete next month as we move briefly onto the analogue-to-digital converter, and experiment with measuring temperature. We will return later to create a standalone SPI driver and add the SPI bus 'read' functionality.

In the mix

I took a break from writing last weekend to attend the Dublin Maker Fair, a one-day event 'showcasing the invention, creativity and resourcefulness of the maker movement' – in other words, hobbyists sharing their creations. From robotic sewing machines to newspaper baskets, animated dragon heads and homemade musical instruments, it was a wonderful event, and great to see youngsters learning to solder for the first time. In the tent next to us were a group of academics with a machine equipped with a dozen syringes controlled by servomotors; we never did find out what it was for! These Maker Fairs are appearing in most major cities now, so do look out for one if you haven't been – they are yearly events the world over. We're hooked!

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at ***@MikeHibbett****, and from his blog at* ***mjhdesigns.com***

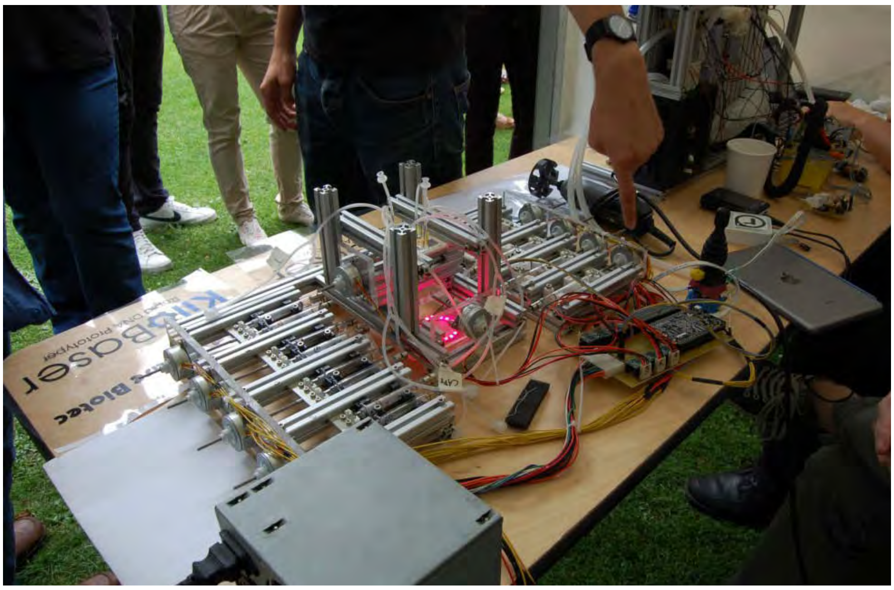

Fig.5. Dublin Maker Fair demo: 'And this?', he asked, pointing to the processor. 'This makes it do stuff!' (It's actually a Microfluidic DNA synthesizer).

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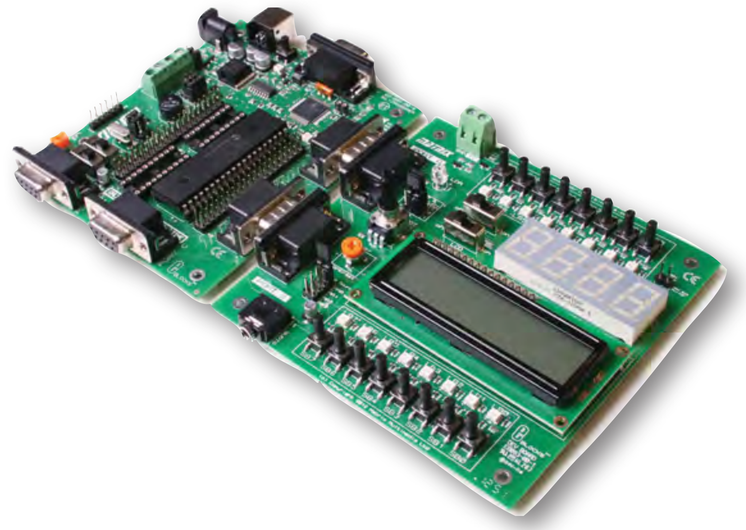

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(Formerly PICtutor)

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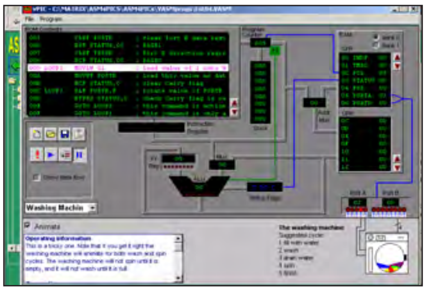

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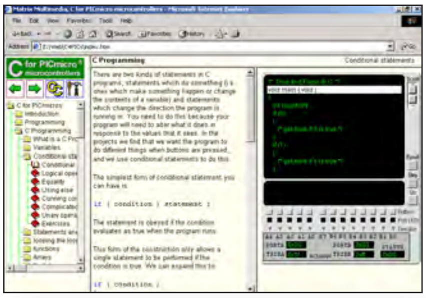

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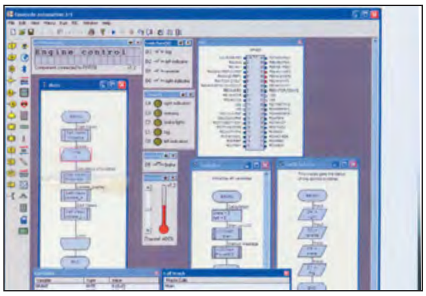

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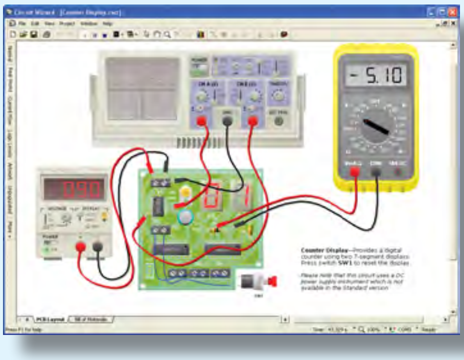

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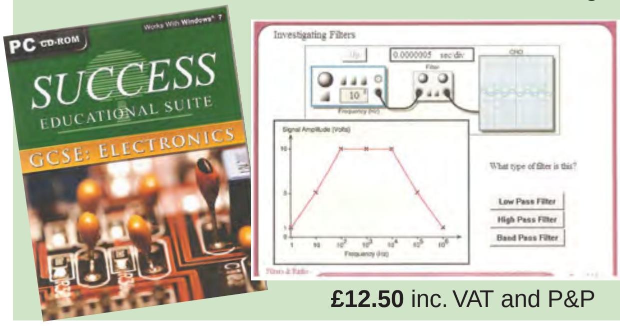

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Max's Cool Beans

By Max The Magnificent

Well, what can I say? As usual, my head is spinning like a top because I am juggling so many balls in the air. The problem being that I can't juggle. Actually, that's not strictly true – I can juggle six fine china plates, but only for a very short period of time.

Current projects

For my last few columns I've been waffling on about my 'Bodacious Acoustic Diagnostic Astoundingly Superior Spectromatic' (BADASS) display project. This is coming along in leaps and bounds, but now my attention is being dragged elsewhere. The thing is, I am easily distracted (oooh, shiny!). This explains why, in addition to all of my existing projects, I've recently added two more to the pile.

But before we talk about these new projects, let me bring you up to date with the current state of play. In addition to my BADASS display, my other big hobby is my 'Pedagogical and Phantasmagorical Inamorata Prognostication Engine' where we understand pedagogical = educational; phantasmagorical = pretty darned fantastic; inamorata = the woman one loves; and prognostication = the foretelling or prophesying of future events.

The idea is to construct an engine that can tell me whether or not the radiance of my wife's smile will fall upon me on any particular day. Of course, if she ever discovers exactly what it is that I'm building, then I don't think I'll need a prognostication engine to determine her mood of the moment.

This is all based on a 'Man vs. Woman' image I first saw on the Internet years ago (**http://bit.ly/1hvRvHv**). Of course, my prognostication engine is going to be a much more splendiferous affair. The control panels are 1/10-inch brass sheets that are going to be festooned with antique knobs and dials and switches and so forth. I'm particularly proud of the five potentiometers that are used to establish the original characteristics associated with one's inamorata, such as the 'Overall Demeanor' control, which ranges from 'Happy-go-Lucky' to 'Be Afraid, Be Very Afraid' (all annotations on the panels are, of course, going to be in Elvish script in order to protect the innocent; ie, yours truly). The thing is, these potentiometers are motorised, so if anyone should disagree with my original settings and tries to modify them, the other potentiometers will automatically change to balance things out (later on, when no one is looking, they will surreptitiously return to their original settings).

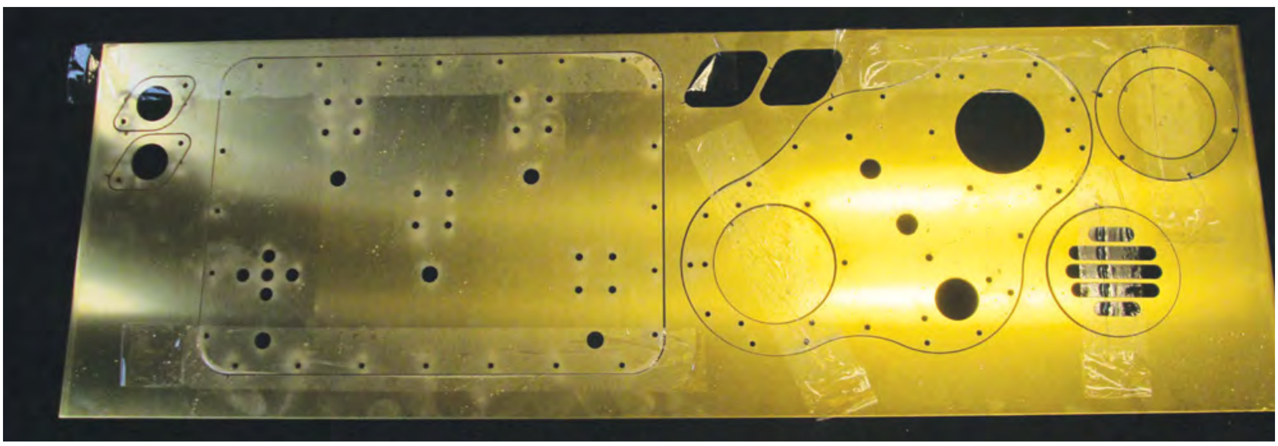
Another feature of the control panels is the use of antique analogue meters with black Bakelite rims, which look superb on the brass panels. The largest of these will be used to reflect the entire range of female emotion, all the way from 'Extremely Disgruntled' to 'Fully Gruntled.'

Boxed up

But I digress... the pseudo electronic equipment in the original 'Man vs. Woman' image had a small 'Man' area and a larger 'Woman' area. In my case, the 'Woman' portion of the system in the form of my Inamorata Prognostication Engine is going to be housed in a beautiful antique wooden radio cabinet from 1929 (an image of this cabinet was shown in my *Cool Beans* column in the May 2014 issue of *EPE*). I always intended for the 'Man' portion of the system – the Ultra-Macho Prognostication Engine – to be housed in a separate wooden box that will sit on top of the radio cabinet. The problem being that I want this box to match the look-and-feel of the radio cabinet. I've been looking for such a box for ages without any luck, until… a few months ago when I met a couple of guys called Bob and Philip who are experts at restoring and/or recreating antique furniture. They've agreed to make the box for me, so the Ultra-Macho Prognostication Engine project is now going full steam ahead (pun intended).

As part of this, I just had the brass panels for the Ultra-Macho Prognostication Engine cut with a water jet. The panels just came back from the machine shop and they are beautiful – as you can see in the photograph below (ignore the sticky tape holding everything together!).

Don't worry about the smaller elements – I'll explain how everything goes together in a future column. The



The brass panels just back from the machine shop

Ultra-Macho Prognostication Engine's main front panel is the curvy-shaped one on the right-hand side of this photograph. This will house the main 'On/Off' switch and a corresponding 'On/Off' light. It will also house a large analogue meter and a pseudo-coal-powered furnace. Meanwhile, the large rectangular panel on the left of this image is going to be mounted on the top of the Ultra-Macho Prognostication Engine (both panels will be recessed into the wooden cabinet). Sticking out of this top panel will be five humongous vacuum tubes, each of which will be illuminated by tri-colored LEDs (check out the YouTube video of my early experiments **http://youtu.be/fEiMlxZCVpA**).

The bottom line is that my BADASS Display, Inamorata Prognostication Engine, and Ultra-Macho Prognostication Engine projects are keeping me more than busy, so the last thing I need is any more projects. But then my chum Steve Manley in England started building himself an 8 × 8 × 8 3D tri-colored LED cube. Even worse, he emailed me pictures showing how cool it looks. I've only got a 4 × 4 × 4 cube. Now I want an 8 × 8 × 8 cube. I couldn't help myself – I am a man with little self-control when it comes to flashing LEDs… I just ordered 512 NeoPixels (plus a few spares) from Adafruit (**www.adafruit.com/products/1734**).

More is more!

But wait, there's more! Another chum – Mike Field (aka 'The Mighty Hamster') who hails from New Zealand – just shared a project idea he's been toying with. He's thinking of creating an Arduino-powered clock that uses antique analogue meters to display the hours, minutes, and seconds. Oooh – this sounds rather cool, but we can make it even cooler – for example, we could add more meters reflecting things like the day of the month and the phase of the moon and… we are limited only by our imaginations.

By some strange quirk of fate, a local annual Hamfest (**www.hamfest.org**) will be taking place in a couple of weeks as I pen these words. When I visited the Hamfest last year, I picked up several of these old meters. It looks like I will be on the hunt for a load more this year – keep your fingers crossed for me. Until next time, have a good one!

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The book applies to Windows 8.1, Windows 8.1 Pro and the vast majority of Windows 8.1 Enterprise. Also parts of the book should be applicable to windows RT 8.1 which is built on the same foundation as Windows 8.1 but is a restricted version designed specifically for ARM tablets.

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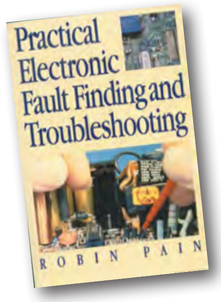

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All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

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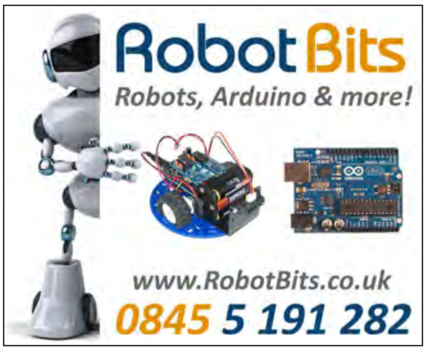

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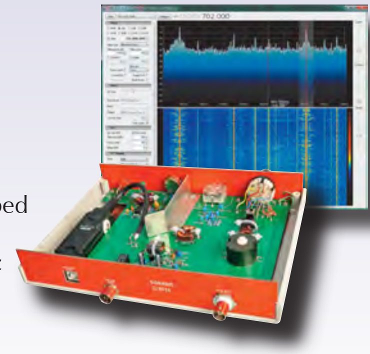
Next Month



SiDRADIO – Part 2

In the current issue, we introduced our *SiDRADIO* communications receiver and described the circuit and PCB assembly. Next month, we will show you how to make and fit the various metal shields and complete the construction by installing your project in a plastic instrument case.

GPS Tracker

This little gadget will precisely record where your car, boat or aeroplane has travelled over time. Using software such as Google Earth you can then see your trips mapped onto the surface of the Earth with a resolution of just a few metres. It's a great device for off-road drivers, sailors, farmers and nomads, and can record a lifetime of travelling on a single SD card.

Hi-Fi Stereo Headphone Amplifier – Part 2

This month (in the October issue) we introduced our new *Hi-Fi Headphone Amplifier* that features very low distortion and noise – it can even drive efficient 8Ω speakers. Next month, we will show you how to build and test it.

Build Your Own PCBs – Part 3

In the third part of this series we will start with a simple PCB design, and show how you can convert the PC-based design into a hand-built board.

NOVEMBER '14 ISSUE ON SALE 2 OCTOBER 2014

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